

Fixed Routing Intelligent Wavelength and Timeslot Reassignment Algorithms for TDM based Optical WDM Networks - Single rate traffic

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Abstract—In this paper, we consider the problem of maximizing the time of first lightpath request rejection, T in the circuit-switched time division multiplexed (TDM) wavelength-routed (WR) optical WDM networks. Given a session request with a specified bandwidth, a lightpath has to be established by using the routing, wavelength and time-slot assignment (RWTA) algorithms. If the lightpath cannot be established, lightpath request rejection or call blocking occurs. As each lightpath is substantial revenue and long-lived, lightpath request rejection is highly unfavourable in the optical backbone networks. In this paper, we are proposing fixed routing, intelligent wavelength and time-slot reassignment algorithms for single rate traffic, where, when a call gets blocked, the already established calls in the network are wavelength and timeslot reassigned so as to accommodate the blocked call. Since we are talking of slow arrivals and long holding times for the lightpaths, it is possible to do this reassignment while provisioning a new call. Simulation based analyses are used to study the performance of these proposed algorithms. The results show that the proposed reassignment algorithms can be used to maximize the time of first call blocking, thereby accommodating more calls in the network before upgrading the network capacity.

I. INTRODUCTION

Wavelength-division multiplexing (WDM) in optical networks is a promising technology to utilize the enormous bandwidth of optical 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. Current optical technology demonstrations have shown the feasibility of up to 160 channels (wavelengths), each operating at 10 Gbps, per fiber [1]. Therefore, WDM technology is very attractive for the backbone networks. In general, topology of a WDM network may be an arbitrary mesh as shown in Figure 1. Traffic between pair of nodes is carried through lightpaths. A lightpath is a high-bandwidth end-to-end circuit between two nodes, occupying a wavelength on each link of the path between the nodes. Nodes are equipped with optical cross connects (OXC) 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 OXC [2]. This work considers the wide area backbone network architecture based on a wavelength-routed mesh topology, in which the nodes do not possess the wavelength conversion capability. Therefore, each lightpath must occupy the same wavelength along all the links of the path which is known as the wavelength continuity constraint [3].

In circuit-switched WR networks, each lightpath (circuit or session) is allocated an entire wavelength for its duration. If the actual bandwidth requirements of the session are less than the channel bandwidth, valuable bandwidth is wasted. Provisioning fractional wavelength capacity is achieved by incorporating time division multiplexing into WDM [5], [6]. In TDM-WDM networks, the bandwidth of the wavelength is partitioned into fixed-length time slots. A session request specifies the number of time-slots required for the session duration. Thus, multiple sessions are multiplexed on each wavelength by assigning a sub-set of the TDM slots to each session. Similar to the wavelength continuity constraint, assigning a slot on a wavelength requires the same time slot on all links along the path on that particular wavelength. This is referred to as the time-slot continuity constraint. In the wide area backbone networks, due to the link propagation and node processing delays, the time-slot allocation on successive links will be shifted. In this work, we assume the link propagation and node processing delays are zero.

Figure 2 shows the single fiber TDM-WDM network. Here, F , the number of slots per wavelength is assumed to be 4. Lightpath between 6 and 2, which has requested for two slots, has been assigned slots 0 and 1 in the first link and the second link. The link propagation and node processing delay is assumed to be 0. Similarly, the time-slot allocations for the session request between nodes 3 and 5 can be seen in the figure. For our work, we have considered single rate traffic, where all the sessions are allowed to request one timeslot only.

In this work, we consider the dynamic version of the circuit-switched network model, where session requests arrive to the network based on some stochastic arrival process. When a

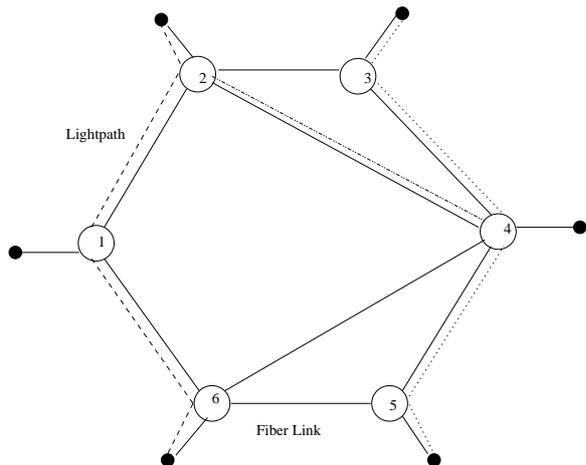


Fig. 1. WDM network consisting of OXC nodes interconnected by fiber links

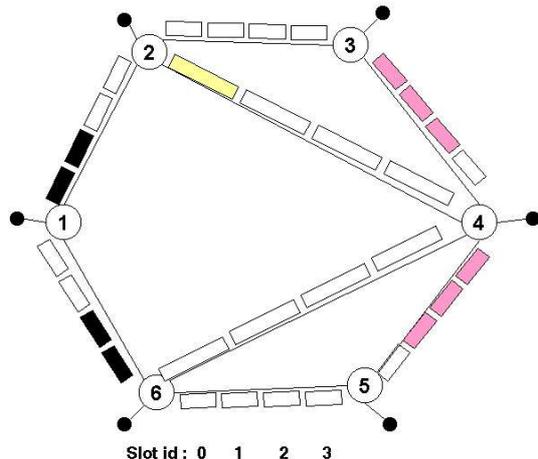


Fig. 2. TDM-WDM network (F=4)

new session request arrives with a specified bandwidth, an all-optical lightpath has to be established between the source and the destination. In order to establish the lightpath, the network has to determine the route, assign the wavelength and allocate time-slots within the wavelength that meets the given request. This is referred to as Routing, Wavelength and Time-slot assignment (RWTA) problem [6]. Once a connection request arrives between a pair of nodes, the centralized algorithm, a single entity, such as a network manager, runs the RWTA algorithms to establish the lightpath for the connection request. If the lightpath cannot be established, then the lightpath request rejection or call blocking occurs.

For the optical backbone networks, lightpaths are long-lived and the average holding time may be of several months or several years. Each lightpath is setup on a provisioning basis. The longevity, combined with the cost of a high-bandwidth lightpath, means that a network operator is unlikely to reject a lightpath request, as it is a significant loss of revenue. In other words, no call must be blocked or the operator would like to increase the time of first lightpath request rejection or call blocking so that, more calls can be accommodated in the network before upgrading the network by the addition of more capacity on the existing links. Therefore, we are proposing fixed routing, intelligent wavelength and time-slot reassignment algorithms, where, when the call gets blocked, the already established calls in the network can be wavelength and timeslot reassigned, so as to establish the blocked call. Simulation based analyses are used to study the resulting improvement in the time of first lightpath request rejection, T for the proposed reassignment algorithm. We have considered, single-fiber TDM-WDM network without wavelength conversion. The simulation results show that, when the call blocking occurs in the network, by employing the proposed reassignment algorithms, maximum traffic can be accommodated in the network before the first call gets blocked.

II. BASIC RWTA ALGORITHM

For routing, the shortest path routing algorithm such as Dijkstra's algorithm [4]–[6] is used to find the shortest path between the source node and the destination node. Fixed routing is used, where alternate path is not considered. Once the shortest path is determined, the next task is to assign the wavelength. For wavelength assignment, the First Fit algorithm [4]–[6] is used. In this scheme, all the wavelengths are numbered. When searching for available wavelength, a lower-numbered wavelength is considered first before higher numbered wavelength. The first available wavelength is then selected. This scheme packs all of the in-use wavelengths towards the lower end of the wavelength space and has a low computation cost. Once the path and the wavelength are determined, then the required time-slots are allocated. For time-slot assignment, the First Fit algorithm [6] is used. This scheme is similar to the first fit wavelength assignment algorithm.

III. PROPOSED REASSIGNMENT ALGORITHMS

In this section, we present the details of the set of proposed reassignment algorithms for the single-fiber TDM-WDM based optical backbone networks supporting dynamic traffic. We define the following before giving the details of the algorithm.

Link Status Matrix $L_{l,K,F}$: The link status is a three dimensional matrix, where l is the number of links in the network, K is the number of wavelengths per link and F is the number of time-slots per wavelength. The link status matrix at any point of time gives the call occupancy in the network, in other words, for the call to be established in the network, what are the links involved in the path, which wavelength is assigned in those links and which are the time-slots allocated in that particular wavelength.

Wavelength Usage: Wavelength usage for a particular wavelength at any point of time gives the usage of that wavelength in the network. This is given by

$$\text{Wavelength Usage} = \frac{\sum_l \text{Time Slots in use}}{l * F} \quad (1)$$

Lower value of wavelength usage indicates, less congested wavelength.

Link Utilization (U): Link utilization for the network at any point of time is given by

$$\text{Link Utilization} = \frac{\sum_K \sum_l \text{Time Slots in use}}{l * K * F} \quad (2)$$

Number of Calls Reassigned (NCR): This gives the number of already established calls in the network that has to be reassigned so as to accommodate the blocked call. This gives the disturbance factor in the network. More is the number of calls that has to be reassigned, higher is the disturbance caused in the network.

A. Reassignment algorithms

When a new session request arrives to the TDM-WDM network, RWTA algorithm determines the route, wavelength and time-slot in that wavelength, so as to establish a lightpath for the request. If the lightpath cannot be established, leading to call blocking then the reassignment algorithms is used to remove this call blocking. We have proposed three reassignment algorithms under fixed routing, intelligent wavelength and timeslot reassignment algorithms.

1) *LC-NLC*: In this technique, we try to shift the already established calls in the overlapping links from the least congested wavelengths to the next least congested wavelength and establish the blocked call in the freed wavelength. A pseudocode description of the algorithm is given below.

When a new call gets blocked,

Step 1: Find the links required for the new call by using the shortest path finding algorithm.

Step 2: From $\mathbf{L}_{l,K,F}$, determine the wavelength usage using equation 1 for all the wavelengths and sort them in the ascending order, forming wavelength usage table. The least congested wavelength is at the top of the table.

Step 3: Try to reassign the existing calls that are occupying the links required from the least congested wavelengths to the next least congested wavelength.

If all the required links are freed by the reassignment, then establish the new call in the freed wavelength.

Else

If there is a next least congested wavelength available from the wavelength usage table, then go to step 3.

Else

Declare that the new call is blocked. At this time of blocking, find U and NCR

Restore the original link status.

Step 4: Go back to the normal RWTA for the next call request arrival.

2) *LC-O*: In this technique, we try to shift the already established calls in the overlapping links from the least congested wavelength to the other wavelengths using the first fit algorithm [4]–[6] and establish the new call in the freed wavelength. The pseudocode is similar to the LC-NLC algorithm, taking into account the necessary changes accordingly.

3) *Random Reassignment Technique [7]*: In this technique, when the new call gets blocked, all the live calls in the network along with the new call are wavelength and timeslot reassigned in a random manner. A pseudocode description is given below. When a new call gets blocked,

Step 1: Find the live calls in the network from the $\mathbf{L}_{l,K,F}$, forming the live call table.

Step 2: Add the new call to the live call table. Number of calls in the live call table is the callcount.

Step 3: Generate a random number which is uniformly distributed between 0 and (callcount-1).

Step 4: Start from this random number in the live call table and establish calls afresh using the RWTA until all the calls in the table are exhausted.

If any call gets blocked, go to step 3. Do this for some number of trials, say 5.

If still all the calls could not be established successfully, declare the at the new call is blocked. At this time of blocking, find U and NCR.

Restore the original link status in the network.

Step 5: Go back to the RWTA algorithm for the next call request.

IV. PERFORMANCE ANALYSIS

This section presents the performance analysis of the proposed reassignment algorithms based on simulation. The results are compared with the RWTA algorithm.

A. Network Model

The network model considered for the simulation is the 14 nodes, 21 links NSFNET backbone network shown in the 3. The network is assumed to be a single-fiber network with no wavelength conversions at the network nodes. The dynamic network traffic is generated in terms of connection requests from a source to destination node. The connection requests arrive at every node according to a Poisson process with rate A_r arrivals per unit time, and uniformly random destination address. Each established connection holds for an exponential distributed period with a mean (μ) of 30 time units. We consider the fixed bandwidth demand for the session requests, which is called the single-rate traffic model. In this model, each connection, requests one time slot bandwidth. Traffic load per node γ , expressed in Erlangs, is given by

$$\gamma = A_r * \mu * \eta \quad (3)$$

where A_r is the mean arrival rate, μ is the mean holding time, η is the mean number of requested slots. In our simulation, $\gamma = A_r * 30 * 1 = 30A_r$ Erlangs.

The metrics used for quantifying the performance of the proposed reassignment algorithms are: the time for first lightpath

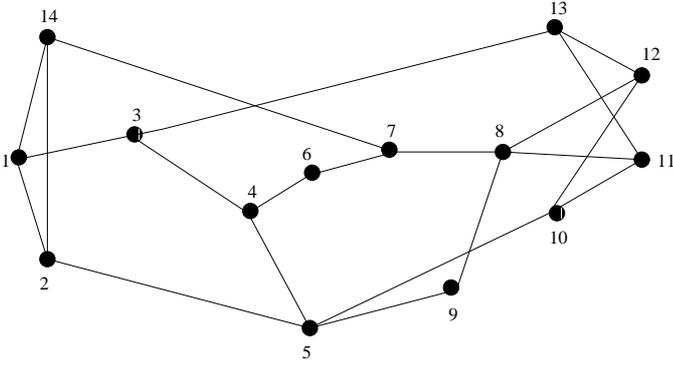


Fig. 3. 14 Nodes, 21 Links NSFNET

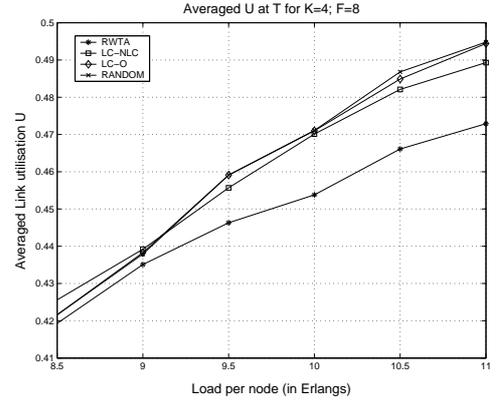


Fig. 5. Link Utilization, U for K=4;F=8

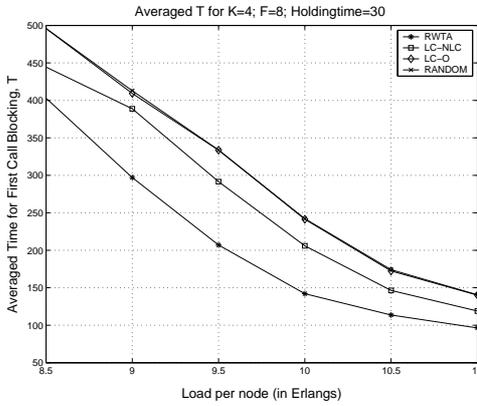


Fig. 4. Time for first call blocking, T for K=4;F=8

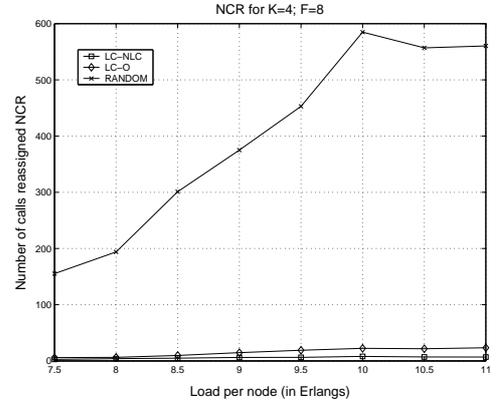


Fig. 6. Number of Calls reassigned before T, NCR for K=4;F=8

request rejection T, link utilization U, the number of calls reassigned, NCR and the probability of blocking, P_b .

B. Performance Evaluation

The network parameters varied for the simulation experiments are K: the number of wavelengths on each link, F: the number of timeslots per wavelength and λ_r : the connection request arrival rate at every node. Simulation experiments were conducted with K=4, F=8 which is equivalent to a WDM network with K=32 and K=8, F=8 which is equivalent to a WDM network with K=64. We present the results for only K=4, F=8 since the performance trends with K=8, F=8 are very similar.

In Figure 4, the time of first call blocking (T) under varying traffic loads is shown. The proposed reassignment algorithms perform better than the RWTA algorithm. The time for first call blocking occurs much latter in the proposed algorithm than the RWTA algorithm. For example, at a load of 10 Erlangs, the proposed reassignment algorithms, LC-NLC shows 45%, LC-O shows 69.95% and Random shows 70.48% improvement from the RWTA algorithm. In Figure 5, the link utilization (U) is plotted under varying traffic loads. It is seen from the figure, at a load of 10 Erlangs, the proposed algorithms give an improvement of around 3.5%. In Figure 6, the number of calls reassigned (NCR) which is the disturbance factor in

the network is plotted under the varying traffic loads. The random reassignment technique has the highest disturbance factor, because when the blocking occurs, all the live calls in the network have to be wavelength and timeslot reassigned. The performance of LC-O technique is equivalent to random technique in terms of T and U (Figure 4, Figure 5) and also it has very less disturbance factor i.e., the number of calls that need to be wavelength and timeslot reassigned is very less in LC-O than the random technique Figure 6. It is seen that LC-NLC has the minimum disturbance factor among all the techniques in Figure 7. As the number of calls reassigned for LC-NLC is less, the performance in terms of T is less compared to other proposed algorithms. In Figure 8, the probability of blocking (P_b) is plotted under varying traffic loads. The proposed algorithms have lower P_b compared to the RWTA as seen in the figure. In terms of P_b , LC-O has the better performance compared to the other techniques.

V. CONCLUSION

Lightpaths carry data at high rates and are long-lived. The longevity combined with the cost of a high-bandwidth lightpath today, means that a lightpath request rejection is a loss of revenue. In this paper, we have proposed fixed routing, intelligent wavelength and timeslot reassignment algorithms to maximize the time for first call blocking in the TDM

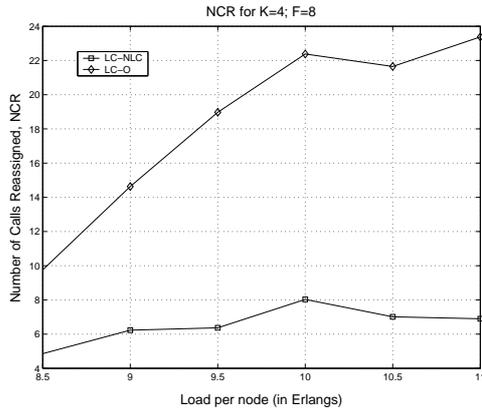


Fig. 7. NCR for first two techniques enlarged, NCR for K=4;F=8

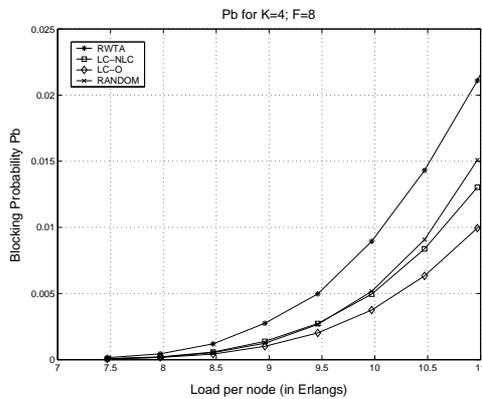


Fig. 8. Probability of blocking, Pb for K=4;F=8

based optical WDM networks. Simulation results show that, before upgrading the network capacity, when the call blocking occurs, these proposed reassignment algorithms can be used to accommodate the blocked call. Among the proposed reassignment algorithms, LC-O has the better performance with less disturbance factor in the network. Since the lightpaths have slow arrivals and long holding times, it is possible to reassign the already established calls in the network while provisioning a new call.

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