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Load Balance RWA Algorithm using Statistical Analysis in WDM Mesh Networks

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Abstract

This study investigates the routing and wavelength assignment (RWA) problem in all-optical wavelength division multiplexing (WDM) mesh networks. The RWA problems can be generally classified as static lightpath establishment (SLE) or dynamic lightpath establishment (DLE). Additionally, the Load Balance RWA (LBRWA) algorithm using the concept of root-mean-square (RMS) which is one of the statistical analysis methods is presented to solve the DLE problem in our study. The proposed algorithm evenly distributes the traffic loads between lightpaths in the RWA process. Simulation results indicate that the proposed algorithm has a lower blocking probability than the Least Loaded Routing algorithm (LLR) and the Maximum Channel Path Routing algorithm (MCPR).

Keywords: RWA, WDM, DLE, RMS

1 Introduction

Wavelength division multiplexing (WDM) in optical fiber networks is rapidly gaining acceptance as an effective means of handling the increasing bandwidth demands of network users. End users in a wavelength-routed WDM network communicate with each other via all-optical WDM channels, called lightpaths [1]. A lightpath supports a connection in a wavelength-routed WDM network, and may span multiple fiber links. Given a set of connections, the problem of setting up lightpaths by routing and assigning a wavelength to each connection request is called the Routing and Wavelength Assignment (RWA) problem.

The RWA problems can be classified as static lightpath establishment (SLE) and dynamic lightpath establishment (DLE) problems [2]. In an SLE problem, also called a virtual topology design problem, the entire set of traffic load between source-destination pairs is known in advance, and the routing and wavelength assignment operations are performed off-line [3]. By contrast, DLE problems adopt the dynamic traffic model, which is also known as the real-time traffic model. In the dynamic traffic model, connection requests arrive randomly, and a lightpath is established for each connection request as the request arrives. Depending on the performance and the complexity of algorithm, adaptive routing can efficiently solve DLE problems [4] by selecting connection request paths according to the network state.

This study focuses on the DLE problem in WDM networks. A novel load balance RWA (LBRWA) algorithm is proposed to balance the traffic load in WDM networks. The load balancing is considered in path computation for each source-destination pair. The proposed algorithm enhances the overall network performance. Previous studies have solved the wavelength assignment and routing problems in two steps. The first step adopts the Dijkstra's algorithm to find the shortest path, using a layered extension of a network graph. Furthermore, the wavelength assignment problem is solved very simply, using uncomplicated sorted wavelength selection processes [5]. When a request arrives, these methods rarely consider the current status of network resource allocation when making the routing decision. Consequently, the traffic load of some links is unbalanced. The network cannot carry any more traffic, even though the network has enough available wavelength resources. The load and resource allocation in the network is asymmetrical, which leads to a high probability of blocking. In addition to these routing policy problems, most network topologies are irregular. Therefore, the network is inherently unbalanced, a factor that should be considered in routing strategies. This study proposes a novel RWA algorithm that considers network state information. The novel algorithm distributes the traffic load evenly along routing path, and thus achieves a low connection blocking rate.

The rest of this paper is organized as follows. Section 2 describes the LBRWA algorithm with a statistical approach to solve the RWA problem. The LBRWA algorithm is compared with other RWA algorithms by simulation in the NSFNET and the USANET network in the Section 3. Finally, the summary is presented in Section 4.

2 The Proposed LBRWA Algorithm

2.1 Statistical Model

The statistical analysis assumes that each node in the network has all information about the entire network. The network topology can be denoted as a graph $G = (V, E, W, F)$, where V represents the set of nodes, and E represents the set of links. Each link consists of a bundle of F fibers, each with W wavelengths. The RWA problem for optical networks with wavelength converters is formulated in terms of a path-link-wavelength vector

$$\left\{X^{w_r}_{p_{s,d},l_k} | p_{s,d} \in P, l_k \in E, w_r \in W\right\}$$

, where $p_{s,d}$ denotes the path from the source node s to destination node d; P denotes the set of all source-destination pairs in the network; l_k denotes the k^{th} link of the topology, and w_r denotes the r^{th} wavelength of the l_k in the network. The variable $X^{w_r}_{p_{s,d},l_k}$ takes a value of 0 or 1, given by

$$X^{w_r}_{p_{s,d},l_k} = \begin{cases} 1 & \text{if wavelength } w_r \text{ is used on link } l_k \text{ by path } p_{s,d} \\ 0 & \text{otherwise} \end{cases}$$

The total traffic load on link $l_k \in E$, M_{l_k} can be expressed statistically in terms of all source-destination pairs pass through link l_k in the network as

$$M_{l_k} = \sum_{p_{s,d} \in P} X^{w_r}_{p_{s,d},l_k} \tag{1}$$

A path can span many links. The total traffic load on path $p_{s,d} \in P$, given by $M_{p_{s,d}}$, can be expressed in terms of M_{l_k} as

$$M_{p_{s,d}} = \sum_{l_k \in L(p_{s,d})} M_{l_k} \tag{2}$$

, where $L(p_{s,d})$ denotes the set of links along path $p_{s,d}$. Then, the degree of load balance on each link of a path is calculated as

$$\sigma = \left[\frac{1}{|L(p_{s,d})|}\left[\sum_{l_k \in L(p_{s,d})} (M_{l_k} - \frac{1}{|L(p_{s,d})|} M_{p_{s,d}})^2\right]\right]^{\frac{1}{2}} \tag{3}$$

, where $|L(p_{s,d})|$ denotes the number of link in path $p_{s,d}$, and σ denotes the root-mean-square value [6] of path $p_{s,d}$, and is measured as the load balance on each link of path $p_{s,d}$. Decreasing σ improves the balance of the traffic load on each link of path $p_{s,d}$ are more balanced.

2.2 Proposed Algorithm

The proposed algorithm attempts to find every connection-path for an arriving routing request. A request is blocked if no path can be found for it. If only one path is found from the source node to the destination node, then it is selected and established for the request; otherwise, if more than one path exists for the request, than all paths are placed in a set $P^s_{s,d}$. The following steps to select a path for the request shown in Fig. 1.

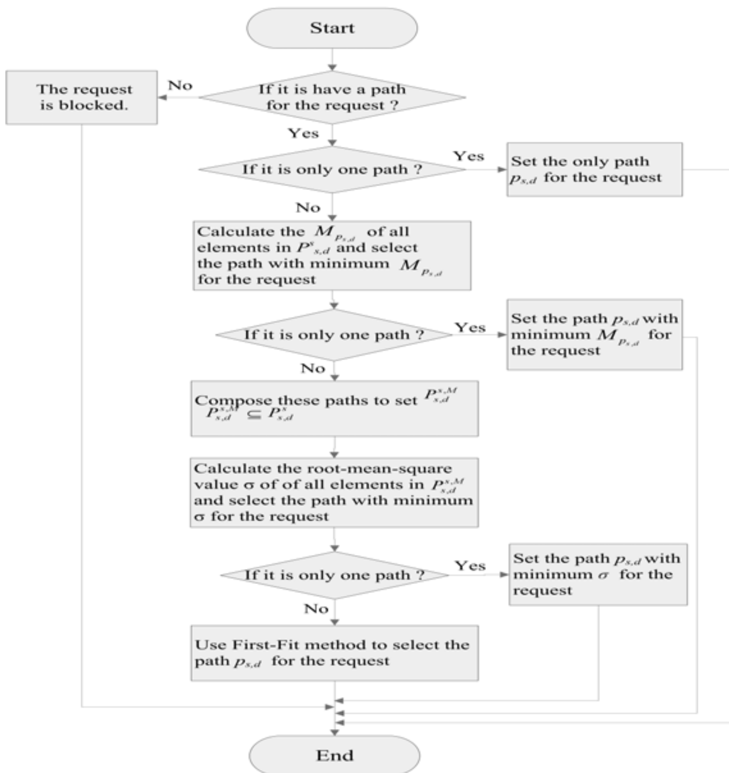

Figure 1: Flowchart of the proposed algorithm

Step 1 : Calculate the cost $M_{p_{s,d}}$for each path in the set $P^s_{s,d}$ using Eqs. (1)-(2), and select the path with the minimum value of $M_{p_{s,d}}$ if available paths exist. If only one path meets the above conditions, then set the path with minimum $M_{p_{s,d}}$ for the request. Otherwise, place these routing paths in a set $P^{s,M}_{s,d}$, $P^{s,M}_{s,d} \subseteq P^s_{s,d}$, and execute Step 2.

Step 2 : Calculate the root-mean-square value σ of all paths in the set $P_{s,d}^{s,M}$ using Equation (3), and select the smallest root-mean-square value. If more than one path in set $P_{s,d}^{s,M}$ has the minimum root-mean-square value, then the First-Fit method is adopted to choose a path to set to $p_{s,d}$.

3 Simulation Result and Discussion

The LBRWA algorithm was evaluated on the NSFNET and the USANET network topologies to prove that the efficiency of the algorithm. The NSFNET topology includes 14 nodes and 21 links, and the USANET topology includes 28 nodes and 45 links. The proposed algorithm was compared with the least loaded routing algorithm (LLR) [5] and the maximum channel path routing algorithm (MCPR) [7].

Both single-fiber and multi-fiber environment were considered in the simulations. Each link has only one fiber (F=1) in a single-fiber network, and four fibers (F=4) in a multi-fiber network. Both single-fiber and multi-fiber networks have 16 wavelengths per fiber (W=16). The arrival of traffic follows a Poisson distribution. The connection requests were distributed randomly on all the network nodes. All simulation results were performed 30 times in order to measure the algorithm performance.

3.1 NSFNET Network Topology

Figure 2 compares the blocking probabilities of the LBRWA algorithm with the LLR and MCPR algorithms in the NSFNET network topology for (a) F=1, W=16, and (b) F=4, W=16. The simulations indicate that the blocking probabilities for the LBRWA, LLR and MCPR algorithms were lower in a multi-fiber environment than in a single-fiber environment, because a multi-fiber environment has more alternative paths than a single-fiber environment, even when the traffic load is heavy. As traffic load increased, the LBRWA algorithm outperformed the LLR and MCPR algorithms for both networks. The simulations indicate that in multi-fiber environment, the LBRWA algorithm distributed the traffic load more evenly than the LLR and MCPR algorithms. LBRWA had a blocking probability of 16% less than LLR, and 6% lower than MCPR, with a full traffic load.

3.2 USANET Network Topology

Figure 3 shows the overall blocking probability versus traffic load for the USANET topologies (a) F=1, W=16, and (b) F=4, W=16. The results in Fig.

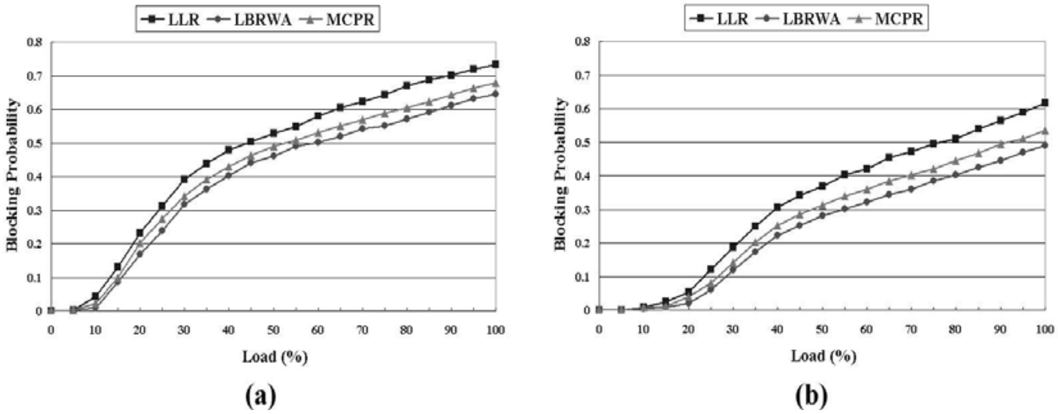

Figure 2: NSFNET Topology with (a) F=1, W=16 (b) F=4, W=16

3 are similar to those in Fig. 2. Both figures indicate that the blocking probabilities in USANET are lower than those of NSFNET in Fig. 2, because USANET has a more complex topology than NSFNET, with more alternative paths. The simulations show that LBRWA, LLR and MCPR improved the blocking probabilities in a multi-fiber environment by 12%, 10% and 8%, respectively with a full traffic load.

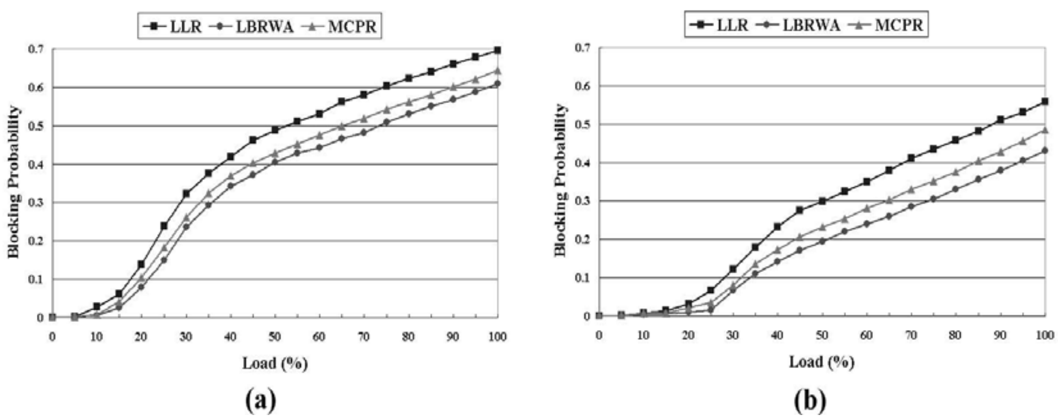

Figure 3: USANET Topology with (a) F=1, W=16 (b) F=4, W=16

4 Conclusions

This study has proposed a novel LBRWA algorithm based on root-mean-square (RMS) to achieve load balance for the WDM network. Simulation results show that the LBRWA algorithm has a lower blocking probability than the LLR and MCPR algorithms for different topologies in the multi-fiber environment, especially in a high traffic load. The traffic load is evenly distributed when many alternative paths are provided. The LBRWA algorithm significantly improves the utilization of network resources.

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