A Dynamic RWA Algorithm for Photonic Networks which Takes Account of Future Demand

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Abstract: A new adaptive RWA (Routing and Wavelength Assignment) algorithm is proposed, which may be used in photonic networks with no wavelength conversion. The problem we address is how to increase the utilization of WDM network resources by taking account of future demand efficiently. In the proposed method, blocking probability is minimized by taking account of future path establishment, using a method for which the computational load is reasonable. Using simulations, we compare the performance of the proposed RWA algorithm with existing methods including fixed-alternate routing and adaptive routing. The results demonstrate that the proposed algorithm can achieve much better blocking performance and the most efficient use network resources.

Keywords: Optical, photonic, WDM, routing, wavelength assignment, RWA, future demand

1. INTRODUCTION

The penetration of broadband access services such as FTTH, xDSL, cable Internet and FWA (Fixed Wireless Access) has been causing a dramatic increase in Internet backbone traffic. Photonic WDM (wavelength division multiplexing) network technology is expected to provide the infrastructure for the backbone network of the next generation Internet, to allow it to cope with such a huge increase in traffic.

A lot of works have been done on using photonic network resources efficiently. One of the hot research topics is the issues of the control scheme and how to set up lightpaths for each connection request in an efficient manner. The authors believe that to minimize blocking probability it is important to consider future demand when establishing lightpaths. Our study is inspired by the recently proposed MIRA (Minimum Interference Routing Algorithm) [1], PBR (Profile-Based Routing) [2], [3] and MOCA (Maximum Open Capacity Routing) [4]. The authors propose a novel RWA algorithm for use in WDM optical networks to achieve efficient network usage. The proposed method takes account of future demand, and achieves this by the very simple method known as the “shortest path” problem, as in Dijkstra’s algorithm of BFS (Breadth First Search). The method allows for future path establishment, at a reasonable computational cost, based on knowledge of the potential ingress-egress node pairs.
1.1. Progress of technologies in IP backbone network

In this section, we review the progress of technologies for the IP backbone network from the viewpoint of routing and forwarding.

MPLS (Multiprotocol Label Switching) is a recently emerged technology which has been applied to provide VPN networks and ensure QoS for the Internet. This can be achieved by explicitly directing packet flows over LSPs (Label Switched Paths) that satisfy QoS requirements.

Up to this point, IP and MPLS forwarding have been executed using electronic processing devices, the speed of which is slow in terms of today’s requirements and, it is widely alleged, follows Moore's law. However, today’s traffic demand has exceeded this law.

GMPLS (Generalized Multiprotocol Label Switching) is a superset protocol which includes the technologies of signaling, routing, and LMP (Link management protocol). GMPLS supports different types of transmission network.

1.2. Photonic network

The technologies of photonic networks eliminate the bottleneck of electronic processing and offer a great potential for coping with future traffic demand in large-scale networks.

In photonic networks, all functions including multiplexing, de-multiplexing and switching are performed by optical processing. Photonic networks are also referred to WDM networks, all-optical networks or wavelength-routed networks. The optical communication path between source and destination is called a lightpath, and this may span over multiple optical links without electronic processing. Multiple lightpaths can use the same optical link only if they use different wavelengths.

Recent developments in WDM technologies make it possible to multiplex more than 250 wavelengths onto a single optical fiber, and each wavelength offers a transmission capacity of 20 Gbps. For these reasons optical WDM technologies have been exhaustively investigated and improved for application to backbone networks.

Photonic networks have a wavelength-routing capability. In a wavelength-routed network, each node incorporates an OXC (Optical Cross Connect), which directly connects an input wavelength signal to an output port without electronic processing (Fig. 1). The incoming
wavelength multiplexed signals are separated at wavelength de-multiplexers (DEMUXs). Next, each individual wavelength signal is routed to a corresponding optical switch. The optical switch switches each incoming signal to an outgoing port on the optical switch based on its routing table. Lastly, each signal is routed to a wavelength multiplexer (MUX) and multiplexed, before being routed to the next node through an optical fiber. When no OXCs through the network have a wavelength conversion capability, a lightpath must use the same wavelength on all the links through the route. This restriction of such an optical network is referred to as the wavelength-continuity constraint.

2. ROUTING AND WAVELENGTH ASSIGNMENT

RWA algorithms can be classified into static and dynamic. In a static RWA, the routing scheme is designed in advance to maximize the number of paths established in the network and the scheme does not vary. Therefore RWA algorithms of this type need to know information about all requests in advance. In contrast, a dynamic RWA uses network state information and calculates a route and assigns a wavelength when a connection request arrives. This type of RWA should be designed to minimize the blocking probability or maximize the network utilization. In this section, we review the dynamic RWA algorithms.

2.1. Previous works

Many dynamic RWA algorithms have been proposed [5-7]. Mokhtar et al. proposed certain adaptive routing and wavelength assignment algorithms and evaluated their blocking characteristics [5]. In adaptive RWA algorithms the route is not limited to a set of pre-determined paths. The algorithms search over the wavelength set until an available path is found using a standard shortest path algorithm. If no path is found, the connection request is blocked. Mokhtar et al. investigated five RWA algorithms which use different mechanisms for sorting of the wavelength set. Here, we describe one of these methods, PACK, which provided the best performance of the five methods in their paper. The PACK method uses a time-varying wavelength utilization vector $U_t=(u_t(0), u_t(1), \ldots, u_t(W-1))$, where $u_t(j)$ denotes the number of links on which the wavelength $j$ is currently used. This algorithm attempts to route the call request on the most utilized wavelength first. That is, the wavelengths are searched in descending order of utilization vector in order to maximize the utilization of available wavelengths.

Chu et al. proposed a weighted least-congestion routing and first-fit (WLCR-FF) RWA algorithm that considers both the number of free wavelengths and the length of each route jointly [6]. WLCR-FF can also be implemented in an environment with sparse or full wavelength conversion. Sparse wavelength conversion means that only part of the nodes in the optical network have the capability of wavelength conversion, while all nodes have wavelength conversion capability in the other situations.

In their algorithm, a set of routes are pre-computed for each source-destination pair which are the edge-disjoint k-shortest paths. Let $\{R_{a1}, R_{a2}, \ldots, R_{am}\}$ denote the set of routes pre-computed for node pair A. When a connection request for node pair “A” arrives, a route must be selected from pre-computed paths. The WCLR-FF algorithm makes a decision based on the weight value $W(R)$, given by the formula below. The route with the maximum weight value is selected to set up the lightpath. The number of free wavelengths on route $R$ is denoted
by $F(R)$ and the length, namely the number of hops, is denoted by $h(R)$.

$$W(R) = \frac{F(R)}{\sqrt{h(R)}}$$

### 2.2. Illustrative examples of shortcoming of the existing method

The shortcomings of existing routing method may be described using a simple network topology. Because connection requests are set up without considering future demand in the existing SP and WLCR-FF algorithms, a bottleneck link may be created which affects future path establishment, leading to a low utilization ratio in a given network. Fig. 2 shows a simple graph with 7 nodes and 7 links, each link having one wavelength. The requests for paths (1, 4) and (7, 4) arrive in this order. Both SP (Shortest Path) and WLCR-FF algorithms select the route 1-5-4 in response to the request (1, 4) since the path 1-5-4 has two hops but 1-2-3-4 has four. This leads to rejection of the next (7, 4) request.

![Fig. 2 An example graph](image)

### 3. ADAPTIVE PATH PREDICTION ROUTING (APPR) ALGORITHM

The authors propose the APPR (Adaptive Path Prediction Routing) algorithm for solving the problem of the dynamic RWA algorithm in WDM optical networks under the wavelength continuity constraint.

#### 3.1. Assumption and objectives

We assume that the network has $N$ nodes, which interconnected by $L$ optical links. $W$ wavelengths are available per optical link. Each node is composed of an OXC without wavelength translation capability. Due to this, lightpaths must use the same wavelength on all fiber links.

It is assumed that potential ingress-egress node pairs are known in advance. However we have no information about future demand. All lightpath setup requests are generated between these pre-specified pairs. Lightpath setup requests arrive dynamically and the lightpaths are set up by determining a route connecting the source to the destination and assigning a free wavelength along the path.

The objective of our proposed dynamic RWA algorithm is to accommodate more traffic by reducing the blocking probability, under the condition of no prior information about future requests, and incurring only a light computational cost.
3.2. Link Cost Calculation

In order to decide the routes to be assigned following lightpath requests, the proposed method uses the minimum cost path calculation using our original idea of link costs. The key idea of proposed algorithm is “anticipation” of future connection requests without prior knowledge. Our method prevents future path establishment requests from being blocked unnecessarily, by saving routes, and thus capacity for future requests, so leading to a reduction in blocking probability.

To accomplish this objective, a high cost weight is assigned to “valuable” links which are critical for future requests and, conversely, a small cost value is assigned to less valuable links. The higher the probability that a link will be utilized by future lightpath requests, the higher the cost weight assigned to it. These “valuable” links are called precious links in this paper.

Next we explain the details behind the idea of link cost assignment. First, for every arrival of a request for a path between a node pair (ex. pair A-B), the MNH (minimum number of hops) paths for each node pair except the requested node pair (i.e. A-B) are computed. The links used by each pair as results of MNH path calculations are defined as precious links in this paper. When several MNH paths are found for a node pair, all of the links involved shall are viewed as precious links for the node pair. Let $\text{num}_{Pl}$ denote the number of node pairs for which link $l$ is a precious link and $\alpha$ a constant number which is greater than or equal to 2. If $\alpha$ is less than 2, we might not reflect anticipation of future demand to weight values. Each link $l$ is assigned a cost weighting $w(l)$ by equation (1).

$$w(l) = \alpha \cdot \text{num}_{Pl} + 1 \quad (1)$$

3.3. Illustrative example of proposed path selection

Future traffic demand is not known in advance. The technique how to calculate weight values, $w(l)$, is explained, when the call request for node pair (1-4) in Fig. 2 is issued.

First, the MNH paths for each node pair except node pair (1-4) are computed. The MNH paths are 7-5-4 for the node pair (7-4) and 6-5-4 for (6-4) respectively. At this time, the MNH path for the node pair (1-4) is not calculated because a lightpath is required between node 1 and 4.

Next, the weight values $w(l)$ of all the links are computed. It is assumed that $\alpha$ is equal to 2. For instance, the way how to compute a $w(l)$ of the link between node 5 and 4, $w(5,4)$, is explained. The number of node pairs for which its link is a precious link is two. That is, its
link is precious link for node pair (7-4) and (6-4). Thus, w(5,4) calculated by equation (1) is 5. In this way, \( w(l) \) of all the links are computed. Fig. 3 shows the graph with weight values applying to the request (1, 4).

In this case, the SP, minimum cost path, between node 1 and 4 is 1-2-3-4. Next, on arrival of request (6, 4), a route 6-5-4 is available, and so that request can be accepted.

3.4. Details of APPR

In this section, the details of the APPR algorithm are explained. A WDM optical network represented by \( G(V, E) \), where \( V \) is set of nodes and \( E \) is set of links, can be treated as layered graph, as shown in Fig. 4. This layered graph consists of \( W \times |X| \) virtual nodes and \( W \times |E| \) virtual links, where \( W \) denotes the number of assigned wavelengths per link and \( |X| \) denotes the number of elements of set \( X \). APPR uses the idea of layered graph at the wavelength selection phase.

![Fig. 4 Layered graph](image)

**APPR (Adaptive Path Prediction Routing)**

**INPUT:**
- A graph \( G(V, E) \) and \( W \) wavelength assigned to each link.
- Ingress-egress node pairs, \( (s_1-d_1), (s_2-d_2), \ldots, (s_P-d_P) \).
- Request for lightpath between an ingress node \( S \) and egress node \( D \).

**OUTPUT:**
- A path and a wavelength between \( S \) and \( D \)

**ALGORITHM:**
1. Select wavelength layer in ascending order (i.e. \( \lambda_0, \lambda_1, \ldots, \lambda_W \)). Assume wavelength \( n \) is selected.
2. As described in section 3.2, compute the weight value \( w(l) \) of all the links over the wavelength layer \( n \) in the graph \( G \) and assign \( w(l) \) to each link.
3. Calculate the shortest path according to \( w(l) \).
4. If a path is found, lightpath is set up over the computed route, and the links over its route are eliminated from the network graph \( G \). If a path is not found over layer \( n \), increment \( n \) to \( n+1 \) and go to 2nd step.
5. If no path is found after checking all wavelength layers, the connection request is blocked.
First a wavelength layer is selected in ascending order (i.e. \( \lambda_0, \lambda_1, \ldots, \lambda_W \)). Next, the link costs over the wavelength layer selected in the previous step are computed as described in section 3.2. Then it is checked whether a route can be found between the requested source and destination. If so, the requested path between the specified ingress and egress node is determined by the shortest (minimum cost) path calculation based on link cost weights. If a route cannot be found, the next wavelength layer is examined for an available path (i.e. return to step 2). If no path is found after checking all wavelength layers, the connection request is blocked.

The APPR algorithm belongs to the type of adaptive routing, in which a routing decision is made every time a call request arrives without the limitation of pre-defined or pre-computed paths. The technique of selecting wavelength in ascending order is very simple to implement. This wavelength selection technique attempts to establish a lightpath on as low a wavelength number as possible, thus saving higher number wavelengths for future requests. The computational requirement for link costs in the APPR is appropriate for a situation which many requests arrive in the short time.

4. SIMULATIONS AND RESULTS

We compared the performance of the proposed adaptive RWA algorithms with adaptive SPF (PACK) [5], WLCR-FF (first-fit) [6] and Fixed-alternate First-Fit Routing (FA-FF) [7].

The network topology shown in Fig. 5 was used to measure the performance of APPR. The number of wavelengths per link is the same for all links. The potential ingress-egress node pairs shown in Fig. 5 are s1-d1, s2-d2, ..., up to s6-d6. The number of lightpath establishment requests is 250.

![Network topology, used in simulations](image)

**Fig. 5 Network topology, used in simulations**

4.1. Simulation 1: uniform request distribution

Fig. 6 shows the number of accepted requests in the simulation of network configuration KL3 (Fig. 5), in which requests were uniformly distributed among the pre-defined ingress-egress node pairs and each link supported 16 wavelengths.

In the case of all the algorithms simulated, none of the first 60 requests was rejected. From the point-of-view of the maximum number of accepted requests, the best performance was achieved by APPR with 110 accepted requests, followed by adaptive SPF with 101, FA-FF with 96 and WLCR-FF with 90. Moreover APPR consistently accommodated the highest number of requests of all methods for all the numbers of requests. In particular, APPR
continued to work effectively when the number of requests exceeded 90 since it sets up lightpaths taking into account future requests. This result shows that the proposed method assigns appropriate weights for future requests to each link for future requests. The APPR shows the best performance of all the routing algorithms simulated.

Fig. 6 Simulation 1: Number of accepted requests with various types of dynamic RWA in network topology KL3 graph

Table 1 Distribution ratio for simulation 2

<table>
<thead>
<tr>
<th></th>
<th>S1-D1</th>
<th>S2-D2</th>
<th>S3-D3</th>
<th>S4-D4</th>
<th>S5-D5</th>
<th>S6-D6</th>
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<td>2</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>1</td>
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</table>

Fig. 7 Simulation 2: Number of accepted requests with various types of dynamic RWA for network topology KL3

4.2. Simulation 2: Weighted requests distribution
A second simulation also has been conducted on the KL3 network topology. The request distribution in simulation 2 differed from the previous simulation, and followed the distribution pattern given in Table 1. The number of accepted requests achieved in simulation 2 is shown in Fig. 7. The maximum number of accepted requests achieved by APPR, Adaptive SPF, WLCR-FF and FA-FF were 105, 99, 93 and 87, respectively. Once again, APPR accommodates the most requests at all times. APPR shows the best performance of all the routing algorithms since it makes routing decisions in which the establishment of path avoids the prevision of a potential bottleneck for future paths. Our proposed method leads to a high utilization ratio in the network.

5. CONCLUSIONS

A novel adaptive RWA algorithm, APPR, has been proposed and evaluated by means of simulations. The proposed algorithm takes account of future requests so as to minimize the blocking probability for path requests without prior knowledge of future demands. However, APPR needs to know the information of all potential ingress-egress node pair.

The results of two simulation experiments clearly show that APPR uses the network resources more efficiently than adaptive-SPF, WLCR-FF and FA-FF. Simulations of other topologies have also been executed. Due to limitations of space, the results of these experiments are not presented, but APPR provided better performance than the other algorithms in these too.

6. FUTURE WORK

The simulation experiments for the dynamic case, where lightpaths are dynamically both set up and torn down, are left for future work. In this simulation technique, APPR will be valuated viewpoint of blocking probability under various traffic conditions. The case of link failure is also a subject for further study.

REFERENCES


