

## Routing Algorithm with Adaptive Weight Function based on Possible Available Wavelength in Optical WDM Networks

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**Abstract:** In this paper, we have proposed a new approach of routing and wavelength assignment algorithms, called Possible Available Wavelength (PAW) algorithm. The weight of a link is used as the main factor for routing decision in PAW algorithm. The weight of a link is defined as a function of hop count and available wavelengths. This function includes a determination factor of the number of wavelengths that are being used currently and are supposed to be available after a certain time. The session requests from users will be routed on the links that has the greatest number of link weight by using Dijkstra's shortest path algorithm. This means that the selected lightpath will have the least hop count and the greatest number of possible available wavelengths. The impact of proposed link weight computing function on the blocking probability and link utilization is investigated by means of computer simulation and comparing with the traditional mechanism. The results show that the proposed PAW algorithm can achieve the better performance in terms of the blocking probability and link utilization.

**Keywords:** Optical WDM Networks, Wavelength Routing, Routing and Wavelength Assignment, Link State Routing Protocol, Adaptive Weight Functions

### 1. INTRODUCTION

Presently, the optical networks based on wavelength division multiplexing (WDM) are considered to be attractive backbone for future wide area networks (WANs). WDM technology offers high capacities with remarkably low error rates while still operating at current electronic speeds by subdividing the optical fiber capacity into multiple channels. In the most of optical networks, the transmitted data remains in the optical domain throughout their transmission paths except at the ends. Such transmission paths are termed as lightpaths [1] as shown in Fig. 1. The lightpaths can be set up and taken down upon demand in a circuit-switched model by wavelength routing. The important of setting up lightpaths is how to perform routing and wavelength assignment for each given connection request that satisfy some desired constraints. This is called the Routing and Wavelength Assignment (RWA) problem [2]. As the complexity of solving the two problems together for optimal performance is very high, these problems are often solved as two independent sub-problems. The first sub-problem deals with routing the connections while the other addresses the wavelength assignment. There are two variants of the problem: (a) static, where the entire set of connections is known ahead of time, and (b) dynamic, where the connection requests arrive based on some stochastic process.

This paper considers the dynamic RWA problem. The primary objective of RWA algorithms is to minimize the congestion or blocking probability in the network. The congestion in a network is defined as the maximum load on any link in the network. The load (utilization) is the ratio of the used capacity to total capacity. The congestion level determines the capacity of the network which translates to network set-up cost. Blocking probability is defined as the ratio of the rejected requests to the total number of requests and a low blocking probability translates to high revenue. The congestion on the network also determines the additional traffic that can be introduced into the network without requiring the installation of additional capacity.

We determine the shortest path from source to destination using Dijkstra's shortest path algorithm, and then assign the

wavelength. In Dijkstra's shortest path algorithm, every link in the network is associated with a weight, for example, the propagation delay of the link. The motivation of this paper is that WDM specific information may be incorporated in the weight functions to improve performance. Therefore, we proposed a new weight function that considers hop count and expected available wavelengths.

The performance investigation of PAW is performed by means of computer simulation. We used Abilene network as a model in the simulation. The metrics studied are blocking probability caused by unavailability of wavelengths and link utilization.

The remainder of the paper is organized as follows. Section 2 presents a summary of other approaches to the RWA problem. Section 3 presents the details of the Possible Available Wavelength (PAW). Section 4 presents the performance evaluation. Finally, the conclusions of this paper are given in Section 5.

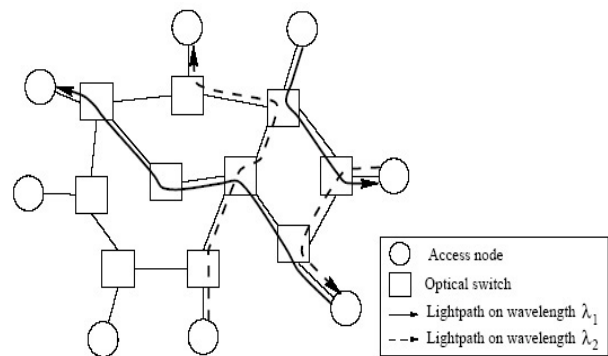


Fig. 1 A wavelength-routed optical WDM network

### 2. RELATED WORKS

Most earlier approaches have chosen to minimize the network congestion by distributing the traffic load evenly to all links. This can be achieved by choosing a path over the least traffic loaded links thereby keeping a few wavelengths

free on all links [2]. The typical approach is to compute the ratio of total wavelengths to free wavelengths [3] as the cost (weight) of a link and then compute the minimum cost path using a link state routing protocol such as Open Shortest Path First (OSPF) [4]. Hence, a lightly traffic loaded link is preferred over a heavily traffic loaded one while choosing a path (next hop) to the destination. Many variants for determining the cost (or weight) of a link such as Hop-based (HW), Distance (DW), Available wavelengths (AW), Hop count and Available wavelengths (HAW), Total wavelengths and Available wavelengths (TAW) and Hop count and Total wavelengths and Available wavelengths (HTAW) have been proposed based on this technique. The comparative studies on these algorithms were performed [3], and HAW was concluded as the best solution.

There are some flaws in the approaches mentioned above. One of them is the assumption that all links are of equal capacity is incorrect. For example, there might be more wavelengths available on a heavily-loaded higher-capacity link than on a lightly-loaded lower-capacity link. The approach to use the load on each individual link to determine its weight is thus flawed. Therefore, a new link weight calculation method, the Expected Available Wavelength (EAW) algorithm is proposed. It calculates paths purely based on the number of available wavelengths. Also included in the new weight function, it is a component that predicts the number of wavelengths that are currently being used but are expected to be available after a certain time [5].

### 3. PAW ALGORITHM

In this section, we assume architecture with a link state routing protocol such as OSPF. The nodes periodically broadcast information on all incident links. Each node independently calculates the shortest route to each destination by implementing Dijkstra's shortest path algorithm [6].

We consider the advantages of adaptive weight function based on expected available wavelengths. Each node maintains an average lifetime of lightpaths for each link based on earlier lightpaths. This average lightpath lifetime is used to predict the number of currently active lightpaths to be torn down thus freeing up wavelengths. This combined with the currently available wavelengths is the average available capacity for the period between the two updates [5]. Then, we choose to improve adaptive weight function based on hop count and available wavelength, HAW achieved best performance in terms of blocking probability, by replacing available wavelengths with expected available wavelengths. On the other hand, we propose a new weight function to calculate the cost of each link. It is a combination of hop count and expected available wavelengths which is named as Possible Available Wavelength (PAW).

For a given link  $(i, j) \in E$ ,  $\lambda_{ij}^a$  denotes the number of available wavelengths on the link when link state information was gathered;  $\lambda_{ij}^t$  denotes the number of total wavelengths on the link; and  $\lambda_{ij}^e$  denotes the number of expected available wavelengths on the link. Then the weight of link  $(i, j)$  or  $w_{ij}$  in PAW algorithm can be formulated as a function in Eq. (1) below [3].

$$w_{ij} = \begin{cases} \alpha - \beta \log \left( 1 - \frac{1}{\lambda_{ij}^e} \right) & \lambda_{ij}^e > 1, \forall (i, j) \in E, \alpha, \beta > 0 \\ \alpha + \beta & \lambda_{ij}^e \leq 1, \forall (i, j) \in E, \alpha, \beta > 0 \end{cases} \quad (1)$$

where

$$\lambda_{ij}^e = \lambda_{ij}^a + \frac{U}{2L_{avg}} (\lambda_{ij}^t - \lambda_{ij}^a)$$

$L_{avg}$  denotes average lifetime of the lightpaths; and  $U$  denotes update interval.  $\alpha, \beta$  are the weights associated with hop count and expected available wavelengths respectively. The calculated  $w_{ij}$  from Eq. (1) is applied into Dijkstra's algorithm as a decision factor. Then, we define that the Dijkstra's algorithm will select the lightpath that has the greatest number of link weight or  $w_{ij}$  along the path. Since, Dijkstra's algorithm is a shortest path routing algorithm, then the selected lightpath in according to proposed link weight function will be the route that has the least hop count and maximum number of expected available wavelengths.

### 4. PERFORMANCE EVALUATION

We studied the performance of PAW by means of computer simulation. The network model used in the simulation is the Abilene network as shown in Fig. 2. Usually, the degree of a node means the number of links that associate with this node. Then in Abilene network, the degree of each node is between 1 and 4. When the total number of nodes is 12 then the average degree of a node is about 3.

The network traffic is generated in terms of connection requests from a source to destination node. The connection requests that arrive at every node are assumed to follow Poisson distribution with a mean of  $\lambda$  connection requests per unit time. The connection duration time is assumed to follow an exponential distribution with a mean of 3 time units. The number of total wavelengths on the link is varied between 8 and 24 by increment of 8. In the following, the simulation uses a first-fit wavelength assignment algorithm for assigning wavelengths and OSPF update interval of 1.0 time units.

The performance parameters considered are:

(1) Blocking Probability refers to the probability that a connection request is blocked due to unavailability of wavelengths for a lightpath.

(2) Link Utilization is given by the percentage of time that all wavelengths of each link in the network are fully utilized.

Figs 3, 4 and 5 present the blocking probability versus link utilization with 8, 16, and 24 wavelengths, respectively. They show a somewhat similar behavior regarding to the blocking probability. It is noticed that when the link utilization is less than the half of the used wavelengths, the blocking probability is extremely low (almost zero). However, in the case of the link utilization is greater than the half of the used wavelengths, the blocking probability increases suddenly and tends to 100 percent of blocking probability. It is implied that all wavelengths are utilized. These results show that the proposed algorithm achieves the better performance in comparing to the traditional mechanism. The processed data for 8, 16, and 24 wavelengths are given in Tables 1, 2 and 3, respectively. They show the blocking probability at certain link utilization. This is achieved by making the average of the blocking probability on a certain interval.



Fig. 2 Abilene network backbone – February 2002

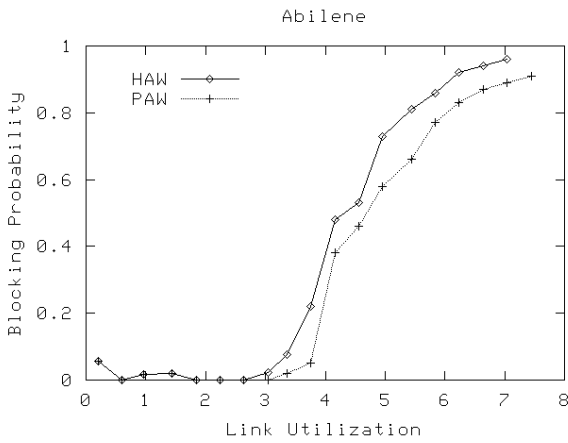


Fig. 3 Blocking probability vs. link utilization with 8 wavelengths

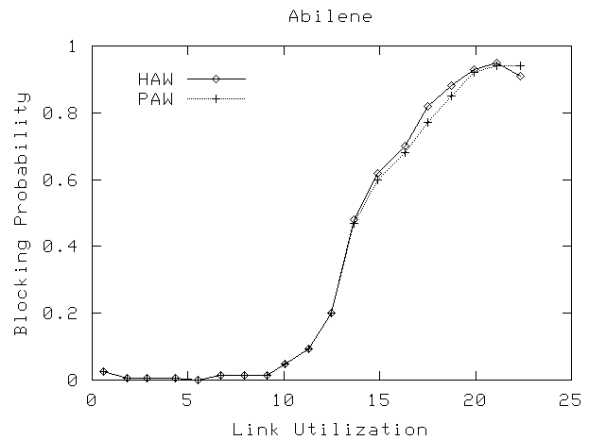


Fig. 5 Blocking probability vs. link utilization with 24 wavelengths

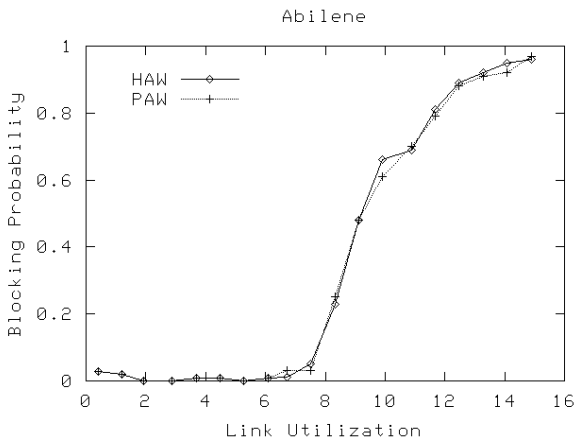


Fig. 4 Blocking probability vs. link utilization with 16 wavelengths

Table 1 Processed data for 8 wavelengths per fibre

HAW	PAW	Link Utilization	
Blocking	Blocking	%	Used wavelengths
0.06	0.06	3	0.24
0.00	0.00	8	0.64
0.02	0.02	12	0.96
0.00	0.00	18	1.44
0.00	0.00	23	1.84
0.00	0.00	33	2.64
0.02	0.00	38	3.04
0.08	0.02	42	3.36
0.22	0.05	47	3.76
0.48	0.38	52	4.16
0.53	0.46	57	4.56
0.73	0.58	62	4.96
0.81	0.66	68	5.44
0.86	0.77	73	5.84
0.92	0.83	78	6.24
0.94	0.87	83	6.64
0.96	0.91	88	7.04

Table 2 Processed data for 16 wavelengths per fibre

HAW	PAW	Link Utilization	
Blocking	Blocking	%	Used wavelengths
0.03	0.03	3	0.4
0.02	0.02	8	1.2
0.00	0.00	12	1.92
0.00	0.00	18	2.88
0.00	0.00	23	3.68
0.00	0.00	33	5.28
0.00	0.00	38	6.08
0.01	0.03	42	6.72
0.05	0.03	47	7.52
0.23	0.25	52	8.32
0.48	0.48	57	9.12
0.66	0.61	62	9.92
0.69	0.70	68	10.88
0.81	0.79	73	11.68
0.89	0.88	78	12.48
0.92	0.91	83	13.28
0.95	0.92	88	14.08
0.96	0.97	93	14.88

Table 3 Processed data for 24 wavelengths per fibre

HAW	PAW	Link Utilization	
Blocking	Blocking	%	Used wavelengths
0.03	0.03	3	0.6
0.00	0.02	8	1.8
0.00	0.00	12	2.88
0.00	0.00	18	4.32
0.00	0.00	23	5.52
0.01	0.01	28	6.72
0.01	0.01	33	7.92
0.01	0.01	38	9.12
0.05	0.05	42	10.08
0.09	0.09	47	11.28
0.20	0.20	52	12.48
0.48	0.47	57	13.68
0.62	0.60	62	14.88
0.70	0.68	68	16.32
0.82	0.77	73	17.52
0.88	0.85	78	18.72
0.93	0.92	83	19.92
0.95	0.94	88	21.12
0.91	0.94	93	22.32

## 5. CONCLUSIONS

This paper studies the Routing and Wavelength Assignment (RWA) problem in optical WDM networks supporting dynamic traffic arrivals. We proposed the Possible Available Wavelength (PAW) weight function, which incorporates the number of hops and expected available wavelengths, for computing shortest-cost paths. We showed that PAW provided the better performance in terms of the blocking probability and link utilization than the traditional mechanism.

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