Efficient wavelength assignment strategy for wavelength-division multiplexing optical networks

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Abstract. When a physical network and its required connections are given, the routing and wavelength assignment (RWA) is a problem. A suitable path and wavelength must be selected from among the many possible choices for each connection such that no two paths using the same wavelength pass through the same link. In the absence of wavelength conversion, a lightpath must use the same wavelength on all fiber links that it spans. In wavelength-division multiplexing (WDM) optical networks, there is a need to maximize the number of connections accepted and to minimize the number of connections rejected, i.e., the blocking probability. We propose a new strategy to assign the wavelength. Then we compare the performance of the proposed strategy with commonly used wavelength assignment strategies in terms of the number of attempts required to establish the given connection. The comparison shows that fewer attempts are required for the proposed strategy, leading to a reduced connection establishment time. [DOI: 10.1117/1.2771580]

Subject terms: WDM; RWA; optical networks; wavelength continuity constraint.

Paper 050986R received Dec. 17, 2005; revised manuscript received Jan. 26, 2007; accepted for publication Mar. 15, 2007; published online Aug. 21, 2007.

1 Introduction

Wavelength-division multiplexing (WDM) is emerging as the dominant technology for next-generation optical networks.[1] It is the most important technique to expand the inherent great capacity of optical fibers. WDM modulates multiple information signals (optical signals) at different wavelengths, and the resulting signals are combined and transmitted simultaneously over the same optical fiber. In order to use WDM on an optical fiber connecting two network nodes, each optical channel is set up on one wavelength by an appropriate tuned laser at the transmitter. Afterward, all wavelengths of the used channels are combined on the fiber by a multiplexer. At the other end of the fiber, a demultiplexer again decodes lightwaves and transfers them to corresponding receivers. An optical network based on WDM using the wavelength routing technique is considered as a very promising approach to realize future large-bandwidth networks.[2] In wavelength routing, data signals are carried on a unique wavelength from a source node to a destination node passing through some intermediate nodes.

In this paper, the Dijkstra's shortest path algorithm is used to find the route from source to destination. A comparison of the performance of the proposed wavelength assignment strategy with the most commonly used existing strategy in terms of the number of attempts to find the wavelength for connection establishment has been presented. This paper is organized as follows. In Sec. 2, we describe the RWA problem in optical networks. In Sec. 3, we describe an existing wavelength assignment strategy. In Sec. 4, we propose an efficient wavelength assignment strategy that reduces the number of attempts required to establish a connection. In Sec. 5, we evaluate the performance of the proposed strategy by taking National Science Foundation NETwork (NSFNET) network. Conclusions are given in Sec. 6.

2 Routing and Wavelength Assignment Problem

In a wavelength-routed WDM optical network, a pair of access stations communicate with one another through a lightpath.[3] Given a set of connection requests, the problem of establishing lightpaths by routing and assigning a wavelength for each connection request is called the RWA problem.[4] The wavelength routed from the source to the destination depends on the availability of the wavelengths at the intermediate links. In a network with no wavelength converters, the lightpath must use the same wavelength from the source to the destination. This is called the wavelength-continuity constraint in wavelength-routed net-

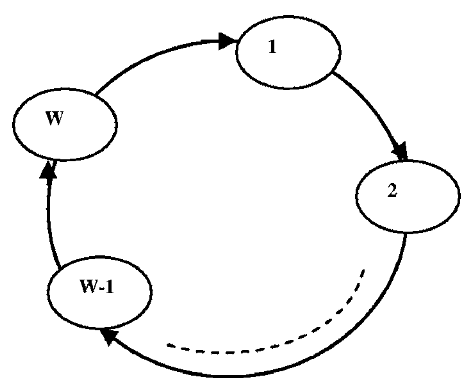

Fig. 1 Arrangement of wavelengths.

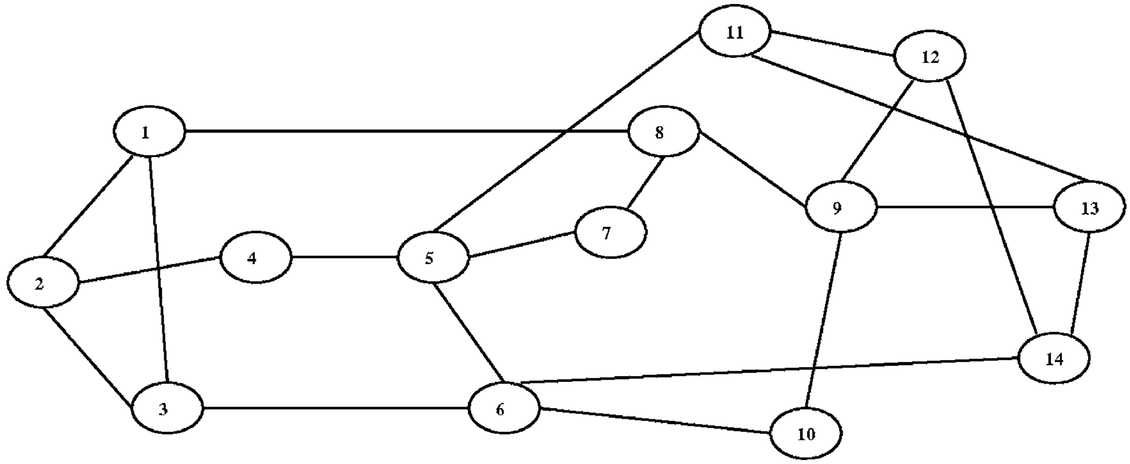

Fig. 2 NSFNET network.

works. The RWA problem deals with routing and assigning wavelengths at every hop in the path.[5,6] Whenever a call arrives at a wavelength router (WR), it will run a predefined algorithm and then select the outgoing port and a wavelength. The shortest-path algorithm can be used to find a route based on the hop count because it selects a route that uses the minimum number of links. When fewer links are used, resources are used more efficiently and the blocking probability is reduced.[7] The selection of the wavelength plays an important role in the algorithm performance and also on the overall blocking probability. Hence, a WR must find the route for the lightpath request and assign a wavelength that minimizes the blocking probability.

RWA schemes can be classified into two categories: static (off-line) or dynamic (on-line).[8] In a static RWA scheme, all the routes and wavelengths for the lightpaths to be set up are fixed initially. Whenever a lightpath request arrives, the RWA scheme assigns the preallocated route and wavelength for that request, so the routing procedure doesn't change with time. A dynamic RWA algorithm uses the current state of the network to determine the route for a given lightpath request. In WDM optical networks, there are three main constraints related with wavelength: wavelength continuity constraint (WCC), distinct wavelength assignment constraint (DWAC), and nonwavelength continuity constraint (NWCC).[9] In WCC, the same wavelength must be used on all the links along the selected route. In DWAC, two lightpaths cannot be assigned to the same wavelength on any fiber. And in NWCC, the different wavelengths can be used on the links along the selected route, but the nodes should have wavelength conversion capability. Wavelength conversion is the ability to convert the data on one wavelength to another wavelength. Eliminating wavelength conversion significantly reduces the cost of the switch, but it also may reduce network efficiency because more wavelengths might be required.

3 Commonly Used Wavelength Assignment Strategies

3.1 *First-Fit (FF) Strategy*

The FF strategy is implemented by predefining an order on the wavelengths.[10,11] A list of used and free wavelengths is maintained. The assignment scheme always chooses the lowest indexed wavelength from the list of free wavelengths and assigns it to the request. By selecting wavelengths in this manner, existing connections will be packed into a smaller number of total wavelengths, leaving a larger number of wavelengths available for longer lightpaths. When the call is completed, the wavelength is added back to the free-wavelength set. But in the FF algorithm, also called the fixed-order algorithm, if multiple connections attempt to set up a lightpath simultaneously, then all lightpaths may choose the same wavelength, leading to one or more connections being blocked due to the nonavailability of the free wavelength on any of the links along the route. This algorithm does not consider the wavelength usage factor, so it does not require the complete connection information. It can be used both with centralized and distributed control.

3.2 *Least-Used (LU) Strategy*

The LU strategy attempts to spread the load evenly across all wavelengths by selecting the wavelength that is the least used on links in the network.[10] This approach ends up breaking the long-wavelength lightpaths quickly; hence, only connection requests that traverse a small number of links will be serviced in the network. This approach requires additional storage and computation costs.

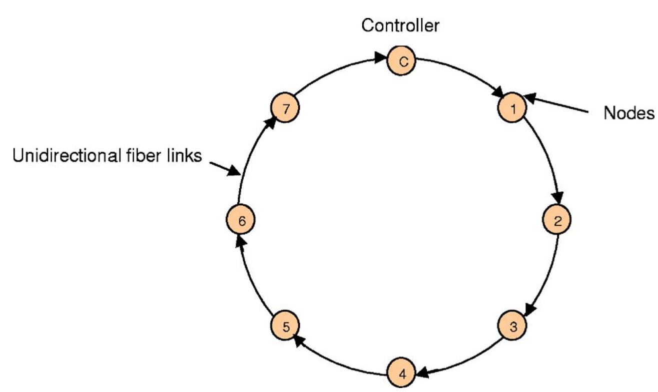

Fig. 3 Unidirectional ring with seven nodes.

Table 1 Comparison table for NSFNET with two wavelengths.

(*s*-*d*) Pairs	Shortest Route	Commonly Used Wavelength Assignment Strategies										Proposed Strategy	
		Least Used		Most Used		First-Fit		Random		Strategy with Tree Topology		Circular Sequential	
		λ no.	No. of attempts	λ no.	No. of attempts	λ no.	No. of attempts	λ no.	No. of attempts	λ no.	No. of attempts	λ no.	No. of attempts
1-9	1-8-9	1	1	1	1	1	1	2	1	1	1	1	1
8-14	8-9-12-14	2	1	2	2	2	2	1	2	D	2	2	1
2-6	2-3-6	1	1	2	1	1	1	1	1	1	1	1	1
12-14	12-14	1	1	1	2	1	1	2	2	2	1	1	2
2-7	2-4-5-7	2	1	2	1	1	1	1	1	1	1	2	1
1-2	1-2	1	1	2	1	1	1	1	1	2	1	1	1
1-7	1-8-7	2	2	2	1	2	2	1	2	2	2	2	1
6-13	6-14-13	1	1	2	1	1	1	2	1	1	1	1	1
3-9	3-6-10-9	2	2	1	2	2	2	2	2	2	2	2	1
4-6	4-5-6	1	1	1	2	2	2	2	1	2	2	1	1
11-14	11-13-14	2	2	1	2	2	2	1	2	2	2	2	1
5-13	5-11-13	1	1	2	1	1	1	2	1	1	1	1	1
Total no. of attempts			15		17		17		17		17		13

Table 2 Comparison table for ring network with three wavelengths.

(*s*-*d*) Pairs	Shortest Route	Commonly Used Wavelength Assignment Strategies										Proposed Strategy	
		Least Used		Most Used		First-Fit		Random		Strategy with Tree Topology		Circular Sequential	
		λ no.	No. of attempts	λ no.	No. of attempts	λ no.	No. of attempts	λ no.	No. of attempts	λ no.	No. of attempts	λ no.	No. of attempts
2-5	2-3-4-5	1	1	1	1	1	1	1	1	2	2	1	1
4-6	4-5-6	3	1	2	2	2	2	3	1	1	1	2	1
1-3	1-2-3	2	1	2	2	2	2	2	2	1	1	3	1
5-7	5-6-7	1	1	1	2	1	1	2	2	2	2	1	1
6-1	6-7-1	2	1	1	2	2	2	3	2	1	1	2	1
4-7	4-5-6-7	D	3	3	3	3	3	D	3	3	3	3	1
2-4	2-3-4	3	1	3	3	3	3	3	2	3	3	2	2
3-4	3-4	2	2	2	3	2	2	2	3	1	1	3	1
Total no. of attempts			11		18		16		16		14		9

3.3 *Most-Used (MU) Strategy*

In MU strategy, the wavelength that is used by most of the links in the network is tried first, then the wavelength with the second-highest number of connections is tried.[10] This algorithm attempts to provide maximum wavelength reuse in the network, leaving maximum wavelengths underutilized. The MU strategy is the opposite of the LU strategy in that it attempts to select the most-used wavelength in the network.

3.4 *Random (RA) Strategy*

Another approach for choosing between different wavelengths is to simply select one of the wavelengths randomly.[12,13] There is no criterion for picking up the wavelength. It can be used with both centralized and distributed control. This approach first searches the wavelengths to find the set of all wavelengths that are available on the required lightpath, and among the available wavelengths, one is chosen randomly.

3.5 *Strategy with Tree Topology (TR)*

This strategy picks up any node randomly, then constructs a tree by using this node as the root and using breadth first search algorithm. It takes all the one-hop count connections and assigns the first free wavelength to this connection.

Table 3 Comparison table for NSFNET with four wavelengths.

(*s*-*d*) Pairs	Shortest Route	Commonly used Wavelength Assignment Strategies										Proposed Strategy	
		Least Used Strategy		Most Used Strategy		First-Fit Strategy		Random Strategy		Strategy with Tree Topology		Circular Sequential	
		λ no.	No. of attempts	λ no.	No. of attempts	λ no.	No. of attempts	λ no.	No. of attempts	λ no.	No. of attempts	λ no.	No. of attempts
1-9	1-8-9	1	1	1	1	1	1	2	1	1	1	1	1
8-14	8-9-12-14	2	1	2	2	2	2	4	1	2	2	2	1
2-6	2-3-6	3	1	2	1	1	1	3	1	2	2	3	1
12-14	12-14	4	1	1	2	1	1	2	1	1	1	4	1
2-7	2-4-5-7	4	1	2	1	1	1	3	1	1	1	1	1
1-2	1-2	1	1	2	1	1	1	3	1	1	1	2	1
1-7	1-8-7	3	1	2	1	2	2	1	1	2	2	3	1
6-13	6-14-13	1	1	2	1	1	1	4	1	1	1	4	1
3-9	3-6-10-9	2	1	1	2	2	2	1	1	3	3	1	1
4-6	4-5-6	3	1	1	2	2	2	2	2	2	2	2	1
11-14	11-13-14	4	1	1	2	2	2	2	2	2	2	3	1
5-13	5-11-13	1	1	2	1	1	1	1	1	1	1	4	1
6-3	6-3	4	3	3	3	3	3	4	2	1	1	2	2
3-5	3-6-5	1	3	4	4	4	4	D	4	4	4	4	2
4-7	4-5-7	2	1	4	3	3	3	4	2	3	3	3	3
10-8	10-9-8	3	1	4	3	3	3	3	3	4	4	4	1
5-14	5-6-14	4	1	3	4	3	3	3	3	3	3	1	1
8-2	8-1-2	2	1	4	3	3	3	4	3	3	3	4	3
5-2	5-4-2	1	2	3	4	4	4	1	4	4	4	3	3
8-5	8-7-5	1	4	1	2	4	4	2	4	4	4	4	1
Total no. of attempts			28		43		44		36		42		28

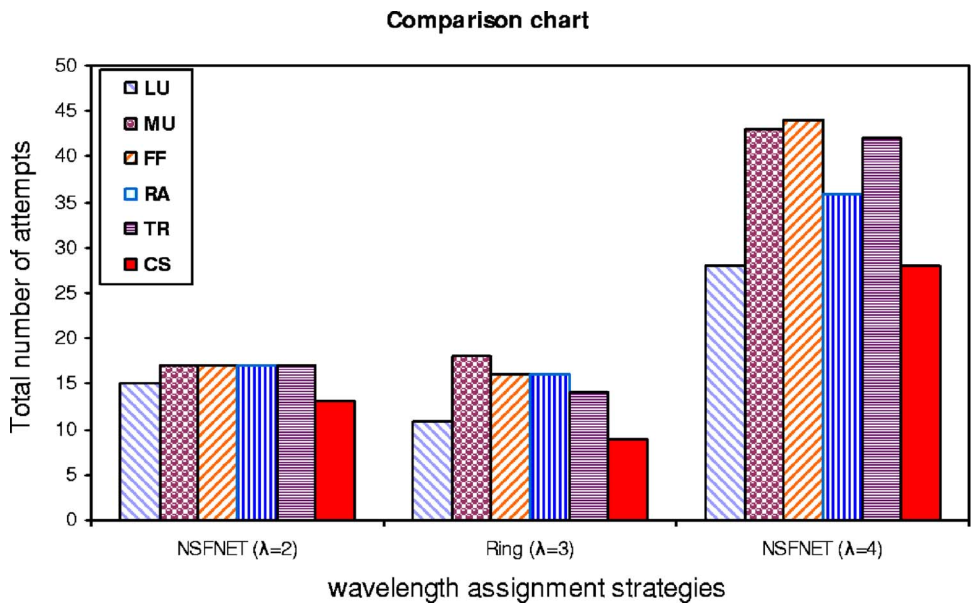

Fig. 4 Comparison chart.

This process is repeated for all the nodes. All the other remaining connections are established with the FF strategy.[14]

4 Circular Sequential (CS) Proposed Strategy

In our proposed CS strategy, a circular list of wavelengths is taken. If W number of wavelengths are available, then they are arranged as shown in Fig. 1. One pointer points to a wavelength. Whenever a connection request arrives, a wavelength assignment is tried starting from the wavelength pointed by the pointer. If the pointed wavelength is free on all the links along the route, a connection is established; otherwise, the pointer proceeds and the next wavelength is tried on the route specified for connection establishment. After the wavelength is assigned, the pointer points to the next wavelength.

The CS algorithm is as follows, where "ptr" means pointer:

1. ptr=1
2. For each source-destination (*s*-*d*) pair, do the following
3. i=ptr
4. Take node pointer j initially pointing to s
5. If wavelength i is not free on link from j to next node on the route, then

(i) if $i=[(\text{ptr}+W) \text{ modulus } W]+1$, then go to step 11
(ii) $i=[(i+W) \text{ modulus } W]+1$
(iii) go to step 4

6. Advance node pointer j to next node on the route
7. If $j\,!=d$, then go to step 5
8. Reserve wavelength i on all the links from s to d on the route to accept the connection request
9. $\text{ptr}=[(i+W) \text{ modulus } W]+1$
10. Go to step 12
11. Reject the connection request
12. Go to step 2 for new *s*-*d* pair till end

5 Results and Discussion

The networks shown in Figs. 2 and 3 are NSFNET[15,16] and unidirectional ring networks, respectively, taken as the sample networks. The paths are wavelength-continuous. The routes have been selected by applying the shortest-path algorithm for NSFNET. First, the following *s*-*d* pairs for connection establishment have been taken for NSFNET with two wavelengths: (1-9), (8-14), (2-6), (12-14), (2-7), (1-2), (1-7), (6-13), (3-9), (4-6), (11-14), and (5-13). Then the following *s*-*d* pairs for connection establishment have been taken for the unidirectional ring with three wavelengths: (2-5), (4-6), (1-3), (5-7), (6-1), (4-7), (2-4), and (3-4). The following *s*-*d* pairs are also considered for NSFNET with four wavelengths: (1-9), (8-14), (2-6), (12-14), (2-7), (1-2), (1-7), (6-13), (3-9), (4-6), (11-14), (5-13), (6-3), (3-5), (4-7), (10-8), (5-14), (8-2), (5-2), and (8-5).

The commonly used wavelength assignment strategies and the CS strategy were applied to the above-mentioned networks and the *s*-*d* pairs. The results are tabulated in Tables 1–3 for NSFNET with two wavelengths, for the ring network with three wavelengths, and for NSFNET with four wavelengths, respectively. These tables compare the number of attempts to find the wavelength for connection establishment for the commonly used and the CS wavelength assignment strategies. Column 1 shows the *s*-*d* pairs; column 2 gives the shortest route from source to destination; and columns 3, 5, 7, 9, 11, and 13 show the wavelengths reserved for connection establishment for the LU, MU, FF, RA, TR, and CS strategies, respectively. The "D" in these columns indicates that the connection could not be established due to the unavailability of a free wavelength. Columns 4, 6, 8, 10, 12, and 14 show the number of attempts to find a free wavelength along the route for the LU, MU, FF, RA, TR, and CS strategies, respectively. One row in the table corresponds to each *s*-*d* pair. The last row indicates the total number of attempts for all the *s-d* pairs for various wavelength assignment strategies. These tables clearly show that in most of the cases, the proposed strategy results in fewer attempts to establish a connection as compared to commonly used strategies. Table 3 shows an equal number of attempts for the LU and CS strategies, but Tables 1 and 2 show better results for CS as compared to LU. Moreover, in the case of the LU strategy, whenever a connection request arrives the system must calculate the uses of each wavelength; but the CS strategy is very simple and does not require this overhead.

Figure 4 compares the commonly used and proposed strategies in the form of a bar graph. The *X* axis represents the sample networks and the number of wavelengths considered. The *Y* axis represents the total number of attempts.

6 Conclusions

In this paper, we have proposed a wavelength assignment strategy that assigns the wavelength in a circular sequential manner. It gives good results because each wavelength has equal importance as it uniformly assigns the wavelengths. The results are taken in terms of the number of attempts to find a free wavelength along the route for connection establishment. The results clearly show that the proposed strategy performs better than commonly used strategies. The number of attempts directly affect the connection establishment time, so with the proposed strategy the connection establishment time is reduced.

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