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Routing and wavelength assignment strategies in optical networks

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Abstract

We consider the routing and wavelength assignment (RWA) problem on wavelength division multiplexing (WDM) networks without wavelength conversion. When the physical network and required connections are given, RWA is the problem to select a suitable path and wavelength among the many possible choices for each connection such that no two paths using the same wavelength pass through the same link. In WDM optical networks, there is need to maximize the number of connections established and to minimize the blocking probability using limited resources. This paper presents efficient RWA strategies, which minimizes the blocking probability. Simulation results show that the performance of the proposed strategies is much better than the existing strategy.

Keywords: WDM; RWA; Optical networks; Wavelength continuity constraint; Shortest path

1. Introduction

Wavelength routing, in conjunction with WDM, appears to be the most promising mechanism for information transport in metropolitan and wide area networks [1]. An optical network based on WDM using the wavelength routing technique is considered as a very promising approach for the realization of future large bandwidth networks. To accommodate several wavelength channels on a fiber, WDM technology can be used as this could enhance the line capacity of the networks. WDM should be used in combination with wavelength routing to enhance the transmission line capacity and cross-connect node processing capability of the large bandwidth networks [2]. In wavelength routing, data signals are carried on single wavelength from source node to destination node.

In WDM optical networks, there are three main constraints related with wavelength assignment: wavelength continuity constraint (WCC), distinct wavelength assignment constraint (DWAC), and nonwavelength continuity constraint (NWCC). In WCC, the same wavelength should be used on all the links along the selected route. In DWAC, two lightpaths cannot be assigned the same wavelength on any fiber and in NWCC, 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 may reduce network efficiency because more wavelengths might be required. But several studies reported that the increased efficiency by using wavelength conversion is small as compared to the cost increase [3,4].

In this paper, we have proposed efficient routing and wavelength assignment strategies, which reduce the blocking probability by reducing the number of connections rejected. The comparison of the proposed routing and wavelength assignment strategies with the commonly used strategy in terms of blocking probability has been presented. This paper is organized as follows. In Section 2, we describe RWA problem in optical networks. In Section 3, we present RWA strategies. Section 4 focuses on performance analysis which shows simulation results by taking an example of realistic NSFNET network. Conclusions are given in Section 5.

2. RWA problem in optical networks

In a wavelength-routed WDM optical network, pairs of access stations communicate with one another through a light-

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path. Given a set of lightpaths that need to be set up, the RWA problem is to route each lightpath and find a wavelength for each. The RWA problem can be considered in two categories according to traffic pattern: static traffic (off-line) and dynamic traffic (on-line) [5]. In the case of static traffic, all lightpath requests are known in advance, thus a routing decision can be made based on the complete knowledge of the traffic to be served by the network. In the case of dynamic traffic, a lightpath request must be routed and wavelength is assigned independently of other lightpaths, which either have been assigned or will be assigned in the future. The objective is to minimize the number of used wavelengths and the call blocking probability and to maximize the number of connections established by the network, i.e., to accommodate maximum connection requests using minimum resources.

If the nodes along the route selected are incapable of converting wavelengths, then it must be assured that a wavelength chosen for the lightpath is available on all links along the chosen route. This is called the wavelength continuity constraint. The problem of selecting an optimal route and a wavelength for a lightpath such that the network throughput is maximized or minimize blocking probability is a tightly coupled problem. Since the tightly coupled RWA problem cannot be analytically solved, it is a general practice to de-couple the problem and try to solve the routing and wavelength assignment problems separately. It is often infeasible to solve the coupled RWA problem for large networks because of the size of the problem [6]. It is more realistic to solve it by decoupling the problem into two separate subproblems, routing subproblem and wavelength assignment subproblem. The objective functions in RWA problem are as follows:

- Given a set of lightpaths, minimize the required number of wavelengths to satisfy these lightpaths without blocking.
- Given a maximum number of wavelengths available, minimize the lightpath blocking probability.

When considered together, the RWA problem seeks to address the question: Given a set of lightpaths that need to be established, what is the best way to achieve it? It could be the minimum number of wavelengths needed to establish the given set of lightpaths or it could be to minimize the blocking probability.

2.1. Routing problem

It is to select an appropriate route from source to destination among all existing routes. If there is more than one choice to select the route, the controller can decide the route according to some heuristics as shortest path routing, load balancing routing, etc. Generally, the fixed shortest-path routing approach is used [7]. The shortest path for each source destination pair is computed off-line in advance using standard shortest-path algorithms, e.g., Dijkstra's algorithm or Bellman–Ford algorithm. The disadvantage of this approach is that the routing decision is not made based on the current state of network. It might lead to the situation where some links on the network are over utilized while other links are underutilized.

2.2. Wavelength assignment problem

Wavelength assignment is to assign the wavelength along the selected route on which data transmission can take place. Proper assignment of wavelengths can lead to reduced or no use of wavelength converters which can significantly reduce the cost. Whenever a call is generated by the source node, it sends the request to the controller. As controller has the knowledge about the network, it contains the information of free and busy wavelengths at that instant of time. Controller then selects a wavelength from the set of free wavelengths and assigns it to that call. To select a wavelength is the critical issues which affects the performance of the network. Mostly used wavelength assignment strategy is first-fit wavelength assignment strategy [2]. It is implemented by predefining an order of the wavelengths. The list of used and free wavelengths is maintained. The assignment scheme always tries to establish the connection using first wavelength, if that wavelength is free on all the links of selected route then connection establishment take place otherwise it will try to establish the connection by using next indexed wavelength and so on up to last wavelength. When the call is completed the wavelength is added back to the free wavelength set.

2.3. Problem formulation

2.3.1. Notations

A: Set of nodes in the network.
B: Set of links in the network.
C: Set of connections.
D: Set of wavelengths.
N: Total number of wavelengths numbered from 0 to $N-1$.
I: Total number of connection requests numbered from 0 to $I-1$.
n: Total number of nodes in the network numbered from 0 to $n-1$.
P_{sd}: Total number of links along the route for sd connection.
s indicates the source.
d indicates the destination.
$sd[j]$ indicates jth connection.
R_{ij} represents the route for the connection when $s=i$ and $d=j$.
W_{ij} represents the wavelength assigned to the connection when $s=i$ and $d=j$.
rejconn is the variable used to store the number of connections rejected.
acconn is the variable used to store the number of connections accepted.

$$W_{ij}^{sd} = 0, \quad \text{if } s\text{–}d \text{ connection does not use any wavelength on link } ij,$$
$$= 1, \quad \text{otherwise.}$$
$$m_{ij,k}^{sd} = 0, \quad \text{if } s\text{–}d \text{ connection does not use wavelength } k \text{ on link } ij,$$
$$= 1, \quad \text{otherwise.}$$

$$Q_{sd}^k = 1, \quad \text{if } s\text{–}d \text{ connection is established on wavelength } k,$$
$$= 0, \quad \text{otherwise.}$$

2.3.2. Mathematical formulations

Total number of s–d pairs (I), if s–d pairs when $s = d$ included, $\forall(s, d \in A)$,

$$= (n(n-1)/2) + n, \quad \text{if } R_{ij} = R_{ji} \text{ and } w_{ij} = w_{ji}\ \forall i,\ j \in A,$$
$$= nxn, \quad \text{otherwise.}$$

Total number of s–d pairs (I), if $s - d$ pairs when $s = d$ excluded, $\forall(s, d \in A)$,

$$= n(n-1)/2, \quad \text{if } R_{ij} = R_{ji} \text{ and } w_{ij} = w_{ji}\ \forall i, j \in A,$$
$$= n(n-1), \quad \text{otherwise.}$$

Blocking probability = rejconn$/I = (I -$ acconn$)/I$.

Objective function = minimize (blocking probability) for fixed number of wavelengths.

Or minimize (N) for zero blocking probability.

Constraints:

1. $\sum_{sd} w_{ij}^{sd} \leqslant N, \quad \forall sd \in C,\ \forall ij \in B.$
   Wavelengths assigned on a link for all the connections does not exceed N.
2. $\sum_{ij}^{sd} m_{ij,k} = P_{sd}, \quad \text{if } Q_{sd}^k = 1,$
   $= 0, \quad \text{otherwise} \quad \forall sd \in C,\ \forall ij \in B, \text{ and } \forall k \in D.$
3. $m_{ij,k}^{sd} = 1, \quad \text{if } w_{ij}^{sd} = 1 \text{ and } Q_{sd}^k = 1,$
   $= 0, \quad \text{otherwise} \quad \forall sd \in C,\ \forall ij \in B, \text{ and } \forall k \in D.$

3. Routing and wavelength assignment strategies

Mostly all the networks employ shortest path for connection establishment. Alternate path is used to establish the connection in the proposed RWA strategies, if the connection could not be established with shortest path. It is because the connections not established with shortest path may get established with alternate path with the available resources to reduce the blocking probability. Alternate paths are more weighed than their corresponding shortest paths, so are given lower priority in the algorithms. These algorithms show the different possible variations of using shortest path with alternate shortest path for first-fit wavelength assignment strategy.

3.1. Existing RWA strategy

3.1.1. RWA 1

In this strategy, shortest path algorithm is used for routing and first-fit wavelength assignment strategy is used for wavelength assignment. For each s–d pair, first of all, try is made to establish the connection on first wavelength using shortest route. If unsuccessful, then connection is tried on second wavelength and so on up to the last wavelength.

3.2. Proposed RWA strategies

3.2.1. RWA 2

In it, the attempt is made to establish the connection for first s–d pair using shortest route starting from first to last wavelength. Now the connection for second s–d pair is tried in the similar way and so on this process is repeated for all s–d pairs. The connection for first s–d pair is tried using alternate route starting from first to last wavelength if connection not established earlier. This step is executed for all other s–d pairs in sequence.

3.2.2. RWA 3

In it, firstly the connections are tried for all the connection requests in sequence using shortest route on first wavelength. Now the similar attempt is made for all the connection requests on all the wavelengths according to their position in indexing. The above mentioned steps are again executed in the same sequence but with alternate route instead of shortest route.

3.2.3. RWA 4

First of all, first connection request is tried using shortest route on the wavelength starting from first to last wavelength. If unsuccessful, the same connection is tried using alternate route on all the wavelengths. The same process is repeated for all the connection requests.

3.2.4. RWA 5

On first wavelength, all the connection requests are tried using their shortest routes. Now the same wavelength is again tried for all the connection requests but with their alternate routes. The above steps are followed for all the wavelengths.

3.2.5. RWA 6

The connection establishment for first s–d pair is tried on first wavelength using shortest route. If unsuccessful, the same connection is tried on same wavelength using alternate route. The same procedure is followed for all the other wavelengths. All the other connection requests are also tried in the same way as the connection establishment for first s–d pair is tried.

3.2.6. RWA 7

It tries for maximum utilization of resources, so that more connections can be established. In this strategy, first of all the attempt is made to establish the connection for first s–d pair using shortest route on first wavelength. If unsuccessful, the same connection request is tried using alternate route on the same wavelength. Now second s–d pair is tried on same wavelength, firstly with shortest route and then with alternate route and so on for all the s–d pairs. In this way, the attempt is made for maximum utilization of first wavelength for connection establishment. It tries to establish maximum connections using the wavelength under consideration. If there is any connection that could have been established using first wavelength either with shortest route or alternate route, it is established. The procedure is followed for all the wavelengths according to the indexing sequence. The attempt of connection establishment is made on any wavelength only if all the wavelengths previous to it in indexing have been tried for all the connection requests with both routes. This strategy gives better results because it utilizes the resources very efficiently.

4. Performance analysis

4.1. Simulation environment

No heuristics could be validated until they are supported by practical results. In order to demonstrate that our approach performs better than that reported in the literature and to investigate the performance of algorithms, we must resort to simulations. Not able to find a suitable simulator that could support our proposed heuristics, we designed and developed a simulator to implement routing and wavelength assignment in all-optical networks for regular and irregular topologies. The simulator is developed in C++ language. It accepts input parameters such as the number of nodes in the network, link information with weight, number of wavelengths per fiber, connection requests. Some of the calls may be blocked because of the unavailability of free wavelength on links along the route from the source to the destination. The ratio of the total number of calls blocked to the total number of lightpath requests in the network is defined as the blocking probability. The output of the simulator is the blocking probability for the specified parameters along with the detailed information of connections. All these parameters can be initialized before running the simulations to obtain results for a given selection of parameters. Extensive simulations are then carried out for every combination of parameters of interest and the obtained results are tabulated.

4.2. Performance evaluation

We have applied proposed RWA algorithms and existing strategy to a realistic example of a backbone network, namely, the NSFNET irregular topology shown in Fig. 1. The nodes are connected together with undirected links. The route from node t to node u will traverse the same links as traversed by the route from node u to node t but in the reverse direction. Permutation routing has been taken for finding out the sample source destination pairs in which every node in the network acts as the source to every other node in the network simultaneously with unicasting approach. Total number of source destination pairs in permutation routing depends upon the number of nodes. The strategies work in the greedy way. If a connection request can be accommodated at any stage, it is accommodated immediately by reserving the resources and the strategies does not try the connection on any other wavelength. Any connection request is first tried using shortest route. The connection could not be established if the wavelength considered is not free on any of the links along the route. The alternate route taken is the route with minimum weight out of all the possible routes which are node and link disjoint with the shortest route so that no link or intermediate nodes are common with the shortest route. With the alternate route, there are chances of connection establishment because the link on which the wavelength was not free with shortest route, does not come in the route.

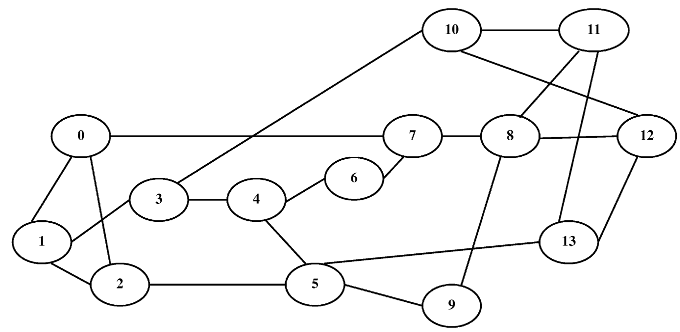

Fig. 1. NSFNET network.

Table 1
Link information table

Link	Weight
0–1	1
0–2	2
0–7	8
1–2	2
1–3	3
2–5	4
3–4	2
3–10	9
4–5	1
4–6	1
5–9	4
5–13	7
6–7	1
7–8	1
8–9	6
8–11	1
8–12	2
10–11	1
10–12	5
11–13	6
12–13	4

Table 1 stores the link information of the network in terms of their weight. Table 2 shows the comparison of existing RWA strategy and proposed RWA strategies in terms of blocking probability. The first column of Table 2 shows the number of wavelengths taken. Column 2 gives the blocking probability for the commonly used existing strategy. Columns 3–8 give the blocking probability for various proposed RWA strategies for comparison purpose. The comparison graph in Fig. 2 shows the results given in Table 2 graphically. X-axis represents the number of wavelengths and the Y-axis represents the blocking probability with permutation routing. The combination difference of the shortest path strategy, alternate shortest path strategy and first fit algorithm between the proposed strategies leads to variation in the performance as shown by the results given in the columns 3–8 of Table 2. Out of these proposed strategies, RWA7 gives the best performance because it efficiently utilizes the resources. Simulation results show that the performance of all the proposed strategies is much better than the existing strategy because proposed strategies use alternate route for connections not established with shortest route.

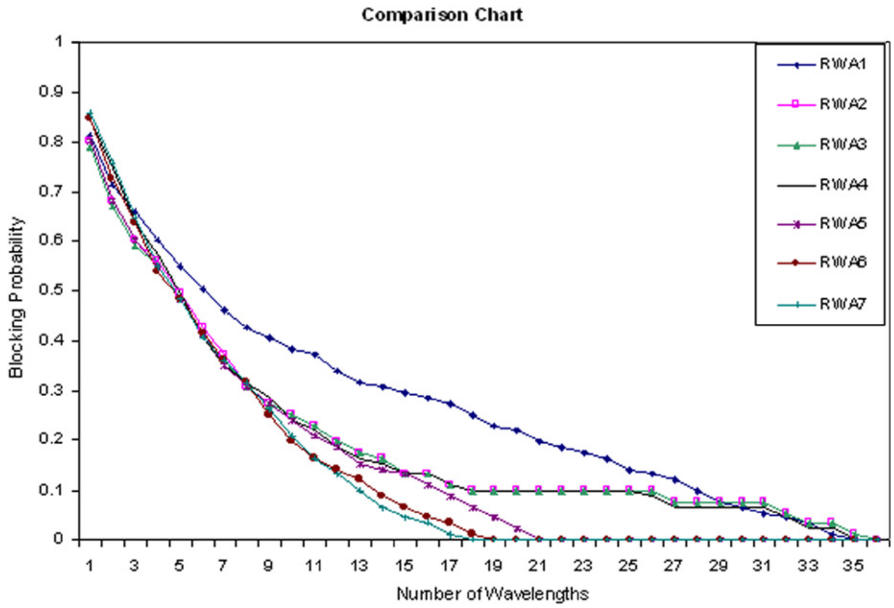

Fig. 2. Comparison graph.

Table 2
Blocking probability comparison table

Number of wavelengths	Blocking probability						
	RWA 1	RWA 2	RWA 3	RWA 4	RWA 5	RWA 6	RWA 7
1	0.813187	0.802198	0.791209	0.846154	0.802198	0.846154	0.857143
2	0.714286	0.681319	0.67033	0.747253	0.681319	0.725275	0.758242
3	0.659341	0.604396	0.593407	0.637363	0.604396	0.637363	0.648352
4	0.604396	0.56044	0.549451	0.571429	0.549451	0.538462	0.549451
5	0.549451	0.494505	0.483516	0.494505	0.483516	0.483516	0.483516
6	0.505495	0.428571	0.417582	0.406593	0.417582	0.417582	0.406593
7	0.461538	0.373626	0.362637	0.351648	0.351648	0.362637	0.362637
8	0.428571	0.307692	0.307692	0.318681	0.307692	0.318681	0.318681
9	0.406593	0.274725	0.274725	0.285714	0.274725	0.252747	0.263736
10	0.384615	0.252747	0.252747	0.241758	0.241758	0.197802	0.208791
11	0.373626	0.230769	0.230769	0.21978	0.208791	0.164835	0.164835
12	0.340659	0.197802	0.197802	0.186813	0.186863	0.142857	0.131868
13	0.318681	0.175824	0.175824	0.164835	0.153846	0.120879	0.098901
14	0.307692	0.164835	0.164835	0.153846	0.142857	0.087912	0.065934
15	0.296703	0.131868	0.131868	0.131868	0.131868	0.065934	0.043956
16	0.285714	0.131868	0.131868	0.131868	0.10989	0.043956	0.032967
17	0.274725	0.10989	0.10989	0.10989	0.087912	0.032967	0.010989
18	0.252747	0.098901	0.098901	0.098901	0.065934	0.010989	0
19	0.230769	0.098901	0.098901	0.098901	0.043956	0	0
20	0.21978	0.098901	0.098901	0.098901	0.021978	0	0
21	0.197802	0.098901	0.098901	0.098901	0	0	0
22	0.186813	0.098901	0.098901	0.098901	0	0	0
23	0.175824	0.098901	0.098901	0.098901	0	0	0
24	0.164835	0.098901	0.098901	0.098901	0	0	0
25	0.142857	0.098901	0.098901	0.098901	0	0	0
26	0.131868	0.098901	0.098901	0.087912	0	0	0
27	0.120879	0.076923	0.076923	0.065934	0	0	0
28	0.098901	0.076923	0.076923	0.065934	0	0	0
29	0.076923	0.076923	0.076923	0.065934	0	0	0
30	0.065934	0.076923	0.076923	0.065934	0	0	0
31	0.054945	0.076923	0.076923	0.065934	0	0	0
32	0.043956	0.054945	0.054945	0.043956	0	0	0
33	0.032967	0.032967	0.032967	0.021978	0	0	0
34	0.010989	0.032967	0.032967	0.021978	0	0	0
35	0	0.010989	0.010989	0	0	0	0
36	0	0	0	0	0	0	0

5. Conclusions

In this paper, we first discussed routing and wavelength assignment problem in WDM optical networks, then the focus was on commonly used routing and wavelength assignment strategy in the optical networks. We have proposed RWA strategies which reduces the blocking probability by reducing the number of connections rejected. Although all the proposed strategies use the shortest path, alternate shortest path and first-fit wavelength assignment strategies giving more priority to shortest path as compared to alternate shortest path, yet differs in the combinations of the three to establish the connections. Each possible combination has been considered. This difference leads to variation in the performance as shown by the results. Out of these proposed strategies, RWA7 gives the best performance because it efficiently utilizes the resources. The performance of proposed strategies and most commonly used RWA have been evaluated in terms of blocking probability by applying on the sample network. Simulation results show that the performance of all the proposed strategies is much better than the existing strategy.

Appendix A. Algorithms for the strategies

1. Existing RWA strategy

RWA 1

1. rejconn = 0.
2. for $j = 0$ to $I - 1$.
3. for $k = 0$ to $N - 1$.
4. try to establish the connection for $sd[j]$ on wavelength k for shortest path.
5. if connection established in step 4
   then go to step 8.
6. end loop for k.
7. rejconn ++.
8. end loop for j.
9. blocking probability = rejconn/I.
10. end.

2. Proposed RWA strategies

RWA 2

1. rejconn = 0.
2. for $j = 0$ to $I - 1$.
3. for $k = 0$ to $N - 1$.
4. try to establish the connection for $sd[j]$ on wavelength k for shortest path.
5. if connection established in step 4
   then go to step 8.
6. end loop for k.
7. rejconn ++.
8. end loop for j.
9. for $j = 0$ to $I - 1$.
10. if connection for $sd[j]$ established with shortest path
    then go to step 17.
11. for $k = 0$ to $N - 1$.
12. try to establish the connection for $sd[j]$ on wavelength k for alternate shortest path.
13. if connection established in step 14
    then (i) rejconn −−, (ii) go to step 17.
14. end loop for k.
15. connection not established.
16. end loop for j.
17. blocking probability = rejconn/I.
18. end.

RWA 3

1. rejconn = I.
2. for $k = 0$ to $N - 1$.
3. for $j = 0$ to $I - 1$.
4. if connection for $sd[j]$ not established earlier
   then try to establish the connection for $sd[j]$ on wavelength k for shortest path
   else go to step 6.
5. if connection established in step 4
   then rejconn −−.
6. end loop for j.
7. end loop for k.
8. for $k = 0$ to $N - 1$.
9. for $j = 0$ to $I - 1$.
10. if connection for $sd[j]$ not established earlier
    then try to establish the connection for $sd[j]$ on wavelength k for alternate path
    else go to step 12.
11. if connection established for $sd[j]$ in step 10
    then rejconn −−.
12. end loop for j.
13. end loop for k.
14. blocking probability = rejconn/I.
15. end.

RWA 4

1. rejconn = 0.
2. for $j = 0$ to $I - 1$.
3. for $k = 0$ to $N - 1$.
4. try to establish the connection for $sd[j]$ on wavelength k for shortest path.
5. if connection established in step 4
   then go to step 12.
6. end loop for k.
7. for $k = 0$ to $N - 1$.
8. try to establish the connection for $sd[j]$ on wavelength k for alternate shortest path.
9. if connection established in step 8
   then go to step 12.
10. end loop for k.
11. rejconn ++.
12. end loop for j.

13. blocking probability = rejconn/I.
14. end.

RWA 5

1. rejconn = I.
2. for $k = 0$ to $N - 1$.
3. for $j = 0$ to $I - 1$.
4. if connection for $sd[j]$ not established with lower wavelength(s)
   then try to establish the connection for $sd[j]$ on wavelength k for shortest path.
   else go to step 6.
5. if connection established in step 4
   then rejconn −−.
6. end loop for j.
7. for $j = 0$ to $I - 1$.
8. if connection for $sd[j]$ not established earlier
   then try to establish the connection for $sd[j]$ on wavelength k for alternate shortest path
   else go to step 10.
9. if connection established in step 8
   then rejconn −−.
10. end loop for j.
11. end loop for k.
12. blocking probability = rejconn/I.
13. end.

RWA 6

1. rejconn = 0.
2. for $j = 0$ to $I - 1$.
3. for $k = 0$ to $N - 1$.
4. try to establish the connection for $sd[j]$ on wavelength k for shortest path.
5. if connection established in step 4
   then go to step 10.
6. try to establish the connection for sd[j] on wavelength k for alternate path.
7. if connection established in step 6
   then go to step 10.
8. end loop for k.
9. rejconn ++.
10. end loop for j.
11. blocking probability= rejconn/I.
12. end.

RWA 7

1. acconn = 0.
2. for $k = 0$ to $N - 1$.
3. for $j = 0$ to $I - 1$.
4. if connection for $sd[j]$ not established with lower wavelengths
   then try to establish the connection for $sd[j]$ on wavelength k for shortest path
   else go to step 8.
5. if connection established in step 4
   then (i) acconn ++, (ii) go to step 8
6. try to establish the connection for $sd[j]$ on wavelength k for alternate path.
7. if connection established in step 6
   then (i) acconn ++, (ii) go to step 8.
8. end loop for j.
9. end loop for k.
10. blocking probability = I − acconn/I.
11. end.

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