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Routing and wavelength assignment in WDM networks with dynamic link weight assignment

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Abstract

We consider the routing and wavelength assignment problem on wavelength division multiplexing networks without wavelength conversion. When the physical network and required connections are given, routing and wavelength assignment (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 wavelength division multiplexing (WDM) optical networks, there is need to maximize the number of connections established and to minimize the blocking probability using limited resources. In this paper, we have proposed three dynamic link weight assignment strategies that change the link weight according to the traffic. The performance of the existing trend and the proposed strategies is shown in terms of blocking probability. The simulation results show that all the proposed strategies perform better than the existing trend.
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Keywords: WDM; RWA; Optical networks; Wavelength continuity constraint; Shortest path

1. Introduction

Optical networks basing on wavelength division multiplexing (WDM) technique is obviously the most promising way to support the huge broadband traffic demand anticipated. Among the study fields related to such optical networks, the routing and wavelength assignment (RWA) of optical paths has been given great attention [1]. 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.

In WDM optical networks, there are three main constraints related with wavelength: *wavelength continuity constraint* (*WCC*), *distinct wavelength assignment constraint* (*DWAC*) *and non-wavelength continuity constraint* (*NWCC*). In WCC, the same wavelength must be used on all the links along the selected route, In DWAC, two light paths cannot be assigned 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 may reduce network efficiency because more wavelengths might be required. But several studies reported that the increased efficiency by using wavelength conversion is small compared to the cost increase [2,3]. The paper examines the case that no wavelength converters exist in the network.

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Notations

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 and are 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
$W_{ij}^{sd}=0$	if s–d connection does not use any wavelength on link ij.
$W_{ij}^{sd}=1$	otherwise
$m_{ij,k}^{sd}=0$	if s–d connection does not use wavelength k on link ij.
$m_{ij,k}^{sd}=1$	otherwise
$Q_{sd}^{k}=1$	if s–d connection is established on wavelength k
$Q_{sd}^{k}=0$	otherwise

In this paper, we have proposed three dynamic link weight assignment strategies that change the link weight according to the traffic, which reduces the blocking probability by symmetrically distributing the traffic to some extent so that more connections can be established. The comparison of the performance of proposed strategies with the existing trend [4–7] 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 system model. In Section 4, we explain link weight assignment strategies. Section 5 focuses on performance analysis which shows simulation results by taking an example of realistic NSFNET network. Conclusions are given in Section 6.

2. RWA problem in optical networks

Given a network topology and a set of end-to-end light path requests, determine a route and wavelength(s) for the requests, using the minimum possible number of wavelengths is called RWA problem [8]. The problem of selecting an optimal route and a wavelength for a light path 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 RWA problems separately. It is often infeasible to solve the coupled RWA problem for large networks because of the size of the problem [9]. It is more realistic to solve it by de-coupling the problem into two separate sub problems, routing sub problem and wavelength assignment sub problem. The objective functions in RWA problem are as follows:

- given a set of light paths, minimize the required number of wavelengths to satisfy these light paths without blocking,
- given a maximum number of wavelengths available, minimize the light path blocking probability.

Routing problem is to select an appropriate route from source to destination among all existing routes. Generally, the fixed shortest-path routing approach is used [10]. The shortest paths 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.

Wavelength assignment problem 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 the controller has the knowledge about the network, it contains the information of free and busy wavelengths at that instant of time. The controller then selects a wavelength from the set of free wavelengths and assigns it to that call. The commonly used wavelength assignment strategy is the first-fit wavelength assignment strategy. 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 the first wavelength, if that wavelength is free on all the links of selected route then the connection establishment takes place otherwise it will try to establish the connection by using the next indexed wavelength and so on up to a total number of wavelengths. When the call is completed, the wavelength is added back to the free wavelength set.

3. System model

The physical network topology is represented as $G(S, L, W)$, in which S represents the set of nodes in the network, L represents the set of links, and W represents the set of wavelengths on each link. A connection request of an s–d pair is served by setting up a light path that is a series of channels belonging to the immediate nodes along the path from the source s to the destination d. The physical topology and the set of connections (C) are given as input for the problem. Our objective is to maximize the number of light paths to be established from the given set of connections.

3.1. Mathematical formulations

Total number of s–d pairs (I) (If s–d pairs when ($s = d$) included), $\forall$ (s, $d \in S$),
$= (n(n-1)/2) + n$, if $R_{ij} = R_{ji}$ and $w_{ij} = w_{ji}$ $\forall i, j \in S$,
$= n \times n$, otherwise.
Total number of s-d pairs (I) (If s-d pairs when ($s = d$) excluded), $\forall$ (s, $d \in S$),
$= n(n-1)/2$, if $R_{ij} = R_{ji}$ and $w_{ij} = w_{ji}$ $\forall i, j \in S$,
$= n(n-1)$, otherwise.
Blocking probability = rejconn/I = (1−acconn)/I.
Objective function = minimize (blocking probability) for fixed number of wavelengths. Or minimize (N) for zero blocking probability.
Constraints:

1. $\sum_{sd} w_{ij}^{sd} <= N, \quad \forall sd \in C, \forall ij \in L.$

Wavelengths assigned on a link for all the connections does not exceed N.

2. $\sum_{ij}^{sd} m_{ij,k} = P_{sd}$, if $Q_{sd}^{k} = 1$.
$= 0$, Otherwise $\forall sd \in C$, $\forall ij \in L$ and $\forall k \in W$.
3. $m_{ij,k}^{sd} = 1$, if $w_{ij}^{sd} = 1$ and $Q_{sd}^{k} = 1$.
$= 0$, Otherwise $\forall sd \in C$, $\forall ij \in L$ and $\forall k \in W$

4. Link weight assignment strategies

Mostly all the networks employ the shortest path for connection establishment. In all the four strategies discussed, first of all the connection establishment corresponding to all the connections is tried on the shortest path because the shortest path helps to utilize the resources efficiently. The alternate shortest path is then used to establish the connection if the connection could not be established with the shortest path with the available resources to reduce the blocking probability in this paper because the connections rejected with shortest path may be established with the alternate path without requiring additional resources [11]. The alternate shortest path for a source destination pair is the path which is link and node disjoint with the shortest path and is least weighted out of all the alternative paths. As it is node and link disjoint, so it will not cover the congested link/node in the shortest path and there are chances of a connection establishment. As alternate paths are more weighed than shortest paths, so are given a lower priority. Always, light paths on shortest routes should be tried before light paths on alternate shortest paths [10]. In all the strategies, the first-fit wavelength assignment technique is used.

4.1. Existing strategy

The network with the given link weight is taken and all the connections are established according to these link weights. The link weights do not change according to the connection requests, the number of wavelengths, the resource requirement/utilization, and resource availability [4–7].

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.

4.2. Proposed strategies

4.2.1. Channel requirement for shortest path (CRSP) strategy

The new weight assigned to a link is equal to the number of channels required on that link if all the connections are to be accepted with the shortest path with the existing strategy. It gives higher weight to the links which are required more number of times, so that they are less preferred for connection establishment, leading in reduction of traffic over these links. Similarly, the links that were in less demand earlier are given low weight so that the traffic on these links increases. In this way, the load gets balanced on the links so that more connections can be accepted reducing the blocking probability. It is independent of the total number of channels on the link i.e. the resources available. The connection requests and the resources required for those are a very important factor and it was not considered in the above-discussed strategy. This strategy changes the link weights according to the connection requests and the resources required for the connection establishment, so gives better results than the existing strategy.

4.2.2. Channel requirement for connection establishment (CRCE) strategy

The new weight assigned to a link is equal to the total number of channels required on that link if the shortest as well as alternate shortest light paths are to be established for all the connection requests with the existing strategy. The load balancing on the links is done according to the resources required and it leads to more number of connections established. In the four strategies discussed, the connection is tried on the alternate shortest path if not established on the shortest path. So the resources required for the alternate shortest path are also equally important as that of the resources required for the shortest path and needs consideration, which is done in this strategy. This consideration was not done in the earlier two discussed strategies, so this strategy performs better than the existing and CRSP strategies. It is independent of the number of wavelengths on the links.

4.2.3. Channel utilization (CU) strategy

In it, the new link weight depends on the total number of channels on a link. The new weight assigned to a link is equal to the total number of channels that will be used on that link for the establishment of all the connections for the given number of wavelengths with the existing strategy. All the links have equal number of channels, but some links are more demanded, so more channels are used on those links and some links are less demanded, so less number of channels is used on those links. If all the links are equally used, then more number of connections can be established. The new link weight assigned tries to give the more priority to the links that were earlier less demanded so that they can be more used by the connections. It also gives less priority to the links that were earlier in more demand so that they are less in demand now. In this way, the traffic gets symmetrically distributed over the links to some extent, thus reducing the blocking probability. It gives best results out of all the four strategies discussed in this paper because it takes into consideration the utilization factor of each link if each link has same resources i.e. number of channels which was not taken care of in the other three strategies.

5. Performance analysis

5.1. 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 algorithm 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 RWA in all-optical networks for regular and irregular topologies. The simulator was developed in the 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 light path 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.

5.2. Performance evaluation

The skeleton of the NSFNET shown in Fig. 1 is a 14-node network with 21 edges. The nodes are connected together with undirected links. We have applied proposed strategies to this network. 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.

Table 1 stores the link information of the network in terms of their weight. Table 2 shows the comparison of existing strategy and proposed link weight assignment 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 3–5 gives the blocking probability for comparison purpose for proposed CRSP, CRCE and CU link weight assignment strategies, respectively. The comparison graph in Fig. 2 shows the results given in Table 2 graphically. The *X*-axis represents the number of wavelengths and the *Y*-axis represents the blocking probability for the sample network with permutation routing. The difference of the link weights among the existing strategy and the proposed strategies leads to variation in the performance as shown by the results given in the columns 2–5

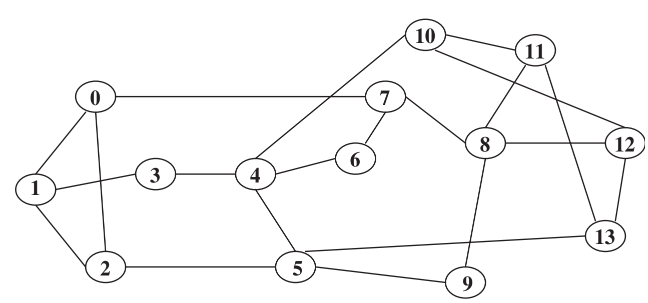

Fig. 1. NSFNET network.

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
5–13	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

of Table 2 although the rest i.e. the physical network topology *G*, the set of connection requests *C*, the routing technique (with shortest and alternate shortest path in this case) and the wavelength assignment strategy (first fit in this case) are the same for all the strategies. All the proposed strategies give better results than the existing approach, but out of all these proposed strategies, CU strategy gives the best performance. Simulation results show that the performance of all the proposed strategies is much better than the existing strategy.

Table 2. Blocking probability comparison table

No. of λs	Existing strategy	CRSP strategy	CRCE strategy	CU strategy
1	0.791209	0.846154	0.835165	0.835165
2	0.681319	0.714286	0.714286	0.725275
3	0.615385	0.626374	0.626374	0.637363
4	0.56044	0.549451	0.582418	0.538462
5	0.505495	0.472527	0.505495	0.450549
6	0.43956	0.428571	0.428571	0.395604
7	0.395604	0.384615	0.384615	0.307692
8	0.340659	0.351648	0.318681	0.263736
9	0.307692	0.285714	0.252747	0.21978
10	0.263736	0.252747	0.208791	0.153846
11	0.241758	0.208791	0.164835	0.131868
12	0.197802	0.186813	0.131868	0.076923
13	0.175824	0.175824	0.076923	0.065934
14	0.153846	0.153846	0.032967	0.021978
15	0.131868	0.10989	0.010989	0.010989
16	0.10989	0.098901	0	0
17	0.10989	0.087912		
18	0.087912	0.087912		
19	0.076923	0.087912		
20	0.076923	0.054945		
21	0.076923	0.043956		
22	0.076923	0.032967		
23	0.076923	0.032967		
24	0.076923	0.021978		
25	0.076923	0.021978		
26	0.076923	0.010989		
27	0.076923	0.010989		
28	0.054945	0.010989		
29	0.032967	0.010989		
30	0.032967	0		
31	0.032967			
32	0.032967			
33	0.032967			
34	0.010989			
35	0			

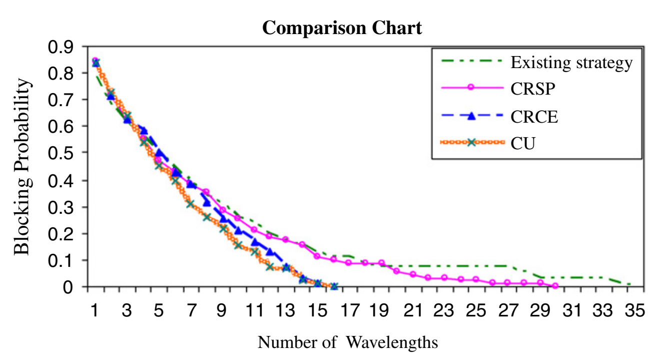

Fig. 2. Comparison graph.

6. Conclusion

In this paper, we discussed RWA problem in WDM optical networks. We have proposed three strategies that aim at load balancing to reduce the blocking probability. In the first proposed strategy, the new link weight is equal to the number of channels required if the shortest path corresponding to all *s–d* pairs are to be established as it assigns the link weight according to the demand of the link so balancing the load. The second proposed strategy further improves the results by also considering the alternate shortest path because it is also equally important. The third proposed strategy gives the best performance by considering the link utilization of each link if each link has equal capacity. The performance of proposed strategies and existing trend has been evaluated in terms of blocking probability by applying on the sample network. The simulation results show that all the three proposed strategies give better results than the existing trend. The third proposed strategy is the best of all these.

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