Available online at www.sciencedirect.com
ScienceDirect
Optik 121 (2010) 679–683
Optik Optics
www.elsevier.de/ijleo

Distributed control based routing and wavelength assignment strategy for WDM optical networks

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Received 4 July 2008; accepted 22 October 2008

Abstract

Wavelength-division-multiplexing (WDM) is emerging as the dominant technology for the next generation optical networks. The control strategy can be either centralized or distributed. In centralized control, there is a central controller to keep track of the state of the network. It is also responsible for selecting the path for data transmission. Most of the work done in this field is based on centralized control. For large networks, distributed control is preferred over centralized control because of low control overhead. Distributed control strategy requires exchange of control messages among nodes. The distributed control generally results in the possibility of resource reservation conflicts among simultaneous path establishments and poor resource utilization. In this paper, we have proposed one distributed control based routing and wavelength assignment strategy that avoids the problem of resource reservation conflicts along with the efficient utilization of resources.

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

1. Introduction

An optical network based on wavelength-division-multiplexing (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 [1]. In wavelength routing, data signals are carried on a unique wavelength from a source node to a destination node.

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 lightpaths 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

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0030-4026/$ - see front matter
doi:10.1016/j.ijleo.2008.10.002

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].

In this paper, we have proposed a distributed based routing and wavelength assignment strategy because distributed control is the only solution for large and scalable networks. Proposed strategy can be used for critical applications as it reserves the resources for a connection in advance. Although it reserves the resources in advance, the resources are utilized very efficiently. The distributed control mostly results in resource reservation conflicts but the proposed scheme totally avoids the conflicts.

This paper is organized as follows. In Section 2, we describe RWA problem in optical networks. In Section 3, we present proposed wavelength assignment strategy. Section 4 focuses on results and discussion by taking an example of realistic NSFNET network. Conclusions are given in Section 5.

2. RWA in WDM networks

In a wavelength-routed WDM optical network, pair of access stations communicates with one another through a lightpath. 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) [4]. 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 wavelengths assigned independently of other lightpaths, which either have been assigned or will be assigned in the future.

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 WCC. 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 decouple 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. It is more realistic to solve it by decoupling the problem into two separate subproblems, routing subproblem and wavelength assignment subproblem. Due to no resource reservation conflicts, these techniques are to be used for reliable systems.

3. Proposed wavelength assignment strategy

The network is assumed to have undirected links by having two parallel fibers or directed links to communicate the data. There is one control fiber that is parallel to the link for each link. This control fiber is bidirectional and will carry the control information between its end nodes. The lightpaths established follow WCC and DWAC constraints. There is one link information table corresponding to each link in the network available with its originating node. The link information table has two columns and one row entry corresponding to each reserved wavelength on that link. The entry in the first column shows the number of the wavelength that has been allocated; second column shows the route for the source destination pair for which this wavelength on this link is reserved. There will be only one route in the second column. The information regarding the connection is conveyed from one end node to another of the link on route because they need to have exact information for proper functioning through the control fiber. If a node has to send some data to any other node, it will find the route to that node. Now a wavelength is to be reserved on all the links along this route to establish the connection for data transmission. The connection is tried to establish on first wavelength, if unsuccessful it is tried on the second wavelength and so on till the last wavelength or till the connection is accepted. Each fiber has equal number of wavelengths.

Starting from the first link on the route to the last node, let us suppose that the link from node i to j is on the route and connection is being tried on kth wavelength. Node i checks the link information table for links i to j and finds out whether there is an entry for wavelength k or not. There will be only one entry at the most for any wavelength in any link information table. If there is a row entry, it means that the wavelength is already reserved and cannot be used for connection establishment. If the wavelength is not free, node i sends the control message to vacate the channel reserved on wavelength k for the connection under consideration to its previous node in the route (if i is not the source for this connection). This previous node (m) deletes the entry in the link information table of link from node m to i for wavelength k and so on till the source node. It also sends the control message to vacate the channel reserved on wavelength k for the connection under consideration to its previous node on the route and so on till the source node.

But if there is no entries in the table of link from node i to j corresponding to wavelength k, it means that wavelength k is free. Now node i, adds one row in the link information table corresponding to link from node i to j. The first column of this row will be having value k and the second column of this row will be having the route. This route information is given, so that when the node gets the information it can direct it to the next node on the route. A control message is send to the node j that directs it to reserve wavelength k for next link on the route if free by making entry in the link information table and to send the control message to the next node on the route (if j is not the destination node). The same process is repeated till destination node comes. Whenever any connection is to be released, if it is from the source side then control message is sent along the route to the nodes directing them to release the wavelength by deleting the corresponding row. If the connection release request is from the destination node, the control message is sent along the route in the reverse direction to direct the nodes to release the wavelength. The resources are released so that they can now be used by other connection requests to accept more number of connections with the available resources.

3.1. Notations

Let N be the number of wavelengths per fiber.
R be the route for lightpath.

3.2. An algorithm

For each source destination pair, the following steps are performed:

1. Source node finds a route R between it and destination.
2. For $i = 1$ to N.
3. Flag = 1.
4. For j = start link to last link on route R.
5. If there is an entry in the link information table corresponding to link j for wavelength i.
   Then
   (I) For $k = j-1$ to start link Step −1.
   (II) Delete the row entry in the link information table corresponding to link k for wavelength i.
   (III) End of for loop for k.
   (IV) Flag = 0.
   (V) Break out of the loop for j.
   Else
   (I) Add one row in the link information table for link j which contains the wavelength i in first column and route R in second column.
   (II) If (j = last link) then connection accepted and break out of the loop for i.
6. End of for loop for j.
7. End of for loop for i.
8. If (Flag = 0) then Reject the connection request.
9. End.

4. Results and discussion

The NSFNET network [2,5] shown in Fig. 1 is taken as the example network. Two wavelengths per fiber have been assumed.

The following source destination (s–d) pairs for connection establishment in the given sequence have been assumed: (2–9), (7–4), (9–13), (5–0), (0–3), (3–13), (1–12), (2–3), (10–4), (5–11), (0–9), (8–13), (6–2), (9–10), (13–11), (10–13) and (3–11).

The network taken is weighted link network. The weight of the link from node i to j will be equal to the weight of the link from node j to i. Table 1 presents the weights of the links taken. The first column of this table gives the link and the second column gives the weight of that link.

Shortest path algorithm is implemented by the nodes to find the route because it results in efficient utilization of resources. As resources are used more efficiently, so more connections can be accepted. It has also been

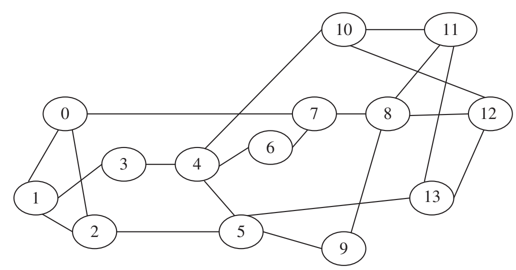

Fig. 1. The 14-node NSFNET.

Table 1. Link weight 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

Table 2. Overview of all the connection requests.

s–d pairs	Route	Wavelength	Status
2–9	2–5–9	1	Accepted
7–4	7–6–4	1	Accepted
9–13	9–5–13	1	Accepted
5–0	5–2–0	1	Accepted
0–3	0–1–3	1	Accepted
3–13	3–4–5–13	2	Accepted
1–12	1–3–4–6–7–8–12	–	Rejected
2–3	2–1–3	2	Accepted
10–4	10–11–8–7–6–4	2	Accepted
5–11	5–4–6–7–8–11	1	Accepted
0–9	0–2–5–9	2	Accepted
8–13	8–12–13	1	Accepted
6–2	6–4–5–2	–	Rejected
9–10	9–8–11–10	2	Accepted
13–11	13–11	1	Accepted
10–13	10–11–13	1	Accepted
3–11	3–4–6–7–8–11	–	Rejected

assumed that no connection was released meanwhile. By applying the proposed algorithm on the above mentioned network and the s–d pairs, the results are tabulated in Table 2. There is one row corresponding to each connection request in this table. Column 1 of this table shows the s–d pair, the second column gives the route for this connection; the third column gives the wavelength reserved if connection established and the last column gives the status of the connection request i.e. accepted or rejected.

The connection from node 1 to 12 was dropped because when it was tried on first wavelength, the link information table available at node 1 for link (1–3) was having entry for first wavelength corresponding to s–d pairs (0–3). So, the connection could not be established on first wavelength. Now it was tried on the second wavelength and the link information table available at node 3 for link (3–4) was having entry corresponding to s–d pairs (3–13) for second wavelength. So, it could not be established on this second and last wavelength and was rejected. Similar is the reason for other dropped connections. This strategy if little modified to look through various routes will although result in acceptance of the connection request dropped e.g. (1–12) etc., but on a longer route and increase in the connection establishment time. The use of longer route will adversely affect the acceptance of another connection requests. Also the increased connection establishment time is undesirable.

Some of the link information tables generated after all the connection requests are considered will be having the information as given in Tables 3(a)–(f). There is one entry corresponding to each reserved wavelength. As two wavelengths per fiber have been assumed so at the most there will be two row entries in the tables. If a link is not used by any of the connections established then there will be a null table corresponding to this link as is the case for link (5–11).

Table 3. Link information tables.

Wavelength	Route
(a) For link 2–5	
1	2–5–9
2	0–2–5–9
(b) For link 5–13	
1	9–5–13
2	3–4–5–13
(c) For link 5–2	
1	5–2–0
(d) For link 10–11	
2	10–11–8–7–6–4
1	10–11–13
(e) For link 11–13	
1	10–11–13
(f) For link 5–11	

5. Conclusions

In this paper, first we have discussed the two types of control: distributed and centralized control. The next section covers the routing and wavelength assignment problem in WDM optical networks. A proposed RWA strategy with distributed control has been discussed in the next section. It results in an efficient utilization of resources. Distributed control which is preferred for large and scalable networks, generally results in resource reservation conflicts. But this problem has been sorted out in this strategy by reserving the resources in advance before data transmission starts by making entry in the link information table. It also makes the system reliable. So this strategy can be used for large and/or scalable networks for handling critical data. It is applied on the standard NSFNET network model and taking some sample s–d pairs. The results and discussion section shows how the strategy avoids the resource reservation conflicts by reserving the resources and making their entry in the link information tables.

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