The Optical WDM Network Link Failure Recovery Based on Bee Colony Optimization

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***Abstract* — This paper considers the problem of optical WDM network recovery due to link failure in the physical network topology. The Bee Colony Optimization (BCO) metaheurictic is used to perform the optical WDM network reconfiguration after the link failure occured. The simulation of single link failure for a given optical network topology is performed and the efficiency of the BCO reconfiguration is compared with the rerouting approach. It is shown that the proposed BCO reconfiguration is more efficient regarding the number of re-established lightpaths after the link failure.**

***Keywords* — Bee Colony Optimization (BCO), Lightpaths, Optical network, Reconfiguration, Rerouting.**

I. Introduction

Optical Wawelength Division Multiplexing (WDM) networks based on wavelength routing technique are rapidly becoming a technology-of-choice to meet the tremendous bandwidth requirements for advanced communication services. A WDM optical network consists of wavelength routing nodes interconnected by point-to-point optical fiber links in an arbitrary (mesh) topology. Due to recent advances in optical switching technology, it is now possible to route the signals in optical domain without O/E/O conversion and eliminate electronic botleneck problem at network nodes. Optical WDM networks in which routing function is performed based on the optical signal wavelength are known as the wavelength routed optical networks (WRON). Several important advantages, such as increased usage of optical fiber bandwidth, reduced processing cost, protocol transparency and efficient network component (link/node) failure handling, have made WRON a realistic solution for future high-speed backbone transport networks.

The main mechanism of communication in WRON is a *lightpath*. A lightpath is circuit-switched communication channel established through the network fully in the optical domain. Each lightpath can carry the data with the rates up to several Gb/s, depending on the end node's equipment processing capability. To establish a lightpath between two nodes, it is necessery to choose a route and to assign one free wavelength over links along that route. This is known as the *routing and wavelength assignment* (RWA) problem. If the wavelength conversion is not possible at network nodes, a lightpath has to be assigned the same wavelength accross all the links along the route. This is known as the *wavelength continuity constraint*. Also, the lightpaths established over the same optical fiber have to be assigned different wavelengths, which is known as the *wavelength distinct constraint*. These two constraints have to be satisfied in WRONs without the wavelenght converters, which are considered in this paper.

This paper considers the link failure recovery problem in wavelength routed optical WDM networks. The amount of traffic carried by a lightpath is typically very large and therefore the fast recovery of service is of great importance, i.e. the recovery time has to be as short as possible.

The paper is organized in the following way. In Section II general approaches for link failure recovery problem in optical networks are considered. Problem statement is given in section III. In Section IV, the numerical results obtained by simulation of lightpath recovery in case of link failure for a given optical WDM network topology are given and compared. Finally, section V gives some concluding remarks.

II. The Link Failure Recovery Techniques

Generally, there are different manners to manage the link failures at the lightpath level in optical WDM networks. Every working (primary) lightpath can be protected by preassigning resources (wavelengths) to its backup (secondary) lightpath. Upon a link failure ocures, every disrupted lightpath is switched to its backup lightpath. In this approach the service recovery is almost immediate since the backup lightpath is readily available. However, it requires excessive resources to be reserved and consequently has the reduced resource uitilisation.

To overcome this shortcoming, instead to preassigning resources for backup lightpaths, they can be dynamically searched after a link failure. However, this approach will result in longer service recovery time and also the resources are not guaranteed to be available.

In this paper, we will consider only the second manner for link failure recovery, based on dynamical resource searching. We will compare two strategies: 1) the lightpath *rerouting* strategy and 2) the *reconfiguration* strategy based on the *BCO* (*Bee Colony Optimization*) metaheuristic. The BCO metaheuristic represents the new direction in the field of *swarm intelligence*. The basic principles of the BCO metaheuristic can be found in [1] - [5].

In the rerouting strategy, the lightpaths that are affected by

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the link failure are routed along alternative physical paths, without affecting other existing lightpaths in given optical network. If there is no available resources along alternative paths, a disrupted lightpath is finally rejected. The principal advantage of this approach is that existing lightpaths that are not affected by the link failure are never disrupted.

In the reconfiguration strategy, all the lightpaths established in given optical network are disrupted for a short period of time and an altogether new logical network topology is computed, by removing a failed link from the physical network topology. It is shown that this approach has the potential to restore more lightpaths than the rerouting approach. We used the Bee Colony Optimization metaheuristic to obtain the reconfigured logical network topology.

III. Problem Statement

Let us assume that a considered optical WDM network physical topology (Fig.1) consists of N=8 routing nodes and L=11 optical links (with two separate fibers for each direction) and with W=4 wavelengths per each fiber. We assume that the traffic demands between source-destination node pairs are initially known and given by the traffic matrix D:

$$D=\left[\begin{array}{c|cccccccc} i\backslash j & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\ \hline 1 & 0 & 1 & 1 & 0 & 1 & 1 & 0 & 1 \\ 2 & 1 & 0 & 1 & 1 & 0 & 1 & 1 & 1 \\ 3 & 1 & 1 & 0 & 1 & 0 & 1 & 1 & 1 \\ 4 & 1 & 0 & 1 & 0 & 1 & 1 & 0 & 1 \\ 5 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 \\ 6 & 1 & 0 & 1 & 1 & 0 & 0 & 1 & 0 \\ 7 & 1 & 0 & 1 & 1 & 1 & 1 & 0 & 1 \\ 8 & 1 & 1 & 0 & 1 & 1 & 0 & 1 & 0 \end{array}\right]$$

Each element $d_{i,j}$ in given matrix D has one of the two possible values:

$$d_{i,j}=\begin{cases}1, & \text{if a lightpath request exists between end nodes } i \text{ and } j\\ 0, & \text{otherwise}\end{cases}$$

The set of established lightpaths (or logical network topology) can be obtained by solving the static RWA problem, which is performed in off-line manner. In [6] we used the ILP (Integer Linear Program) formulation of the static RWA problem in which the number of established lightpaths need to be maximized (MaxRWA). For reasonable network dimensions (up to few nodes), the optimal solution of the MaxRWA problem can be obtained by exact solving the given ILP formulation. In [1] we proposed the BCO metaheuristic algorithm tailored for the MaxRWA problem, which we called the BCO-RWA algorithm. In this paper, we will apply the BCO-RWA algorithm to obtain the new (reconfigured) logical network topology after the physical link failure occurs in a network.

We assume that all the lightpaths in obtained logical topology are currently in progress and that the failure in given network is randomly occured at one physical link. Consequently, all the lightpaths established over that link will be disrupted. Our objective is to solve the link failure recovery problem in given optical network so as to maximize the number of lightpaths after the failure is occured. To achieve this, we will use the reconfiguration approach based on the BCO metaheuristic and compare it's efficiency with the rerouting approach.

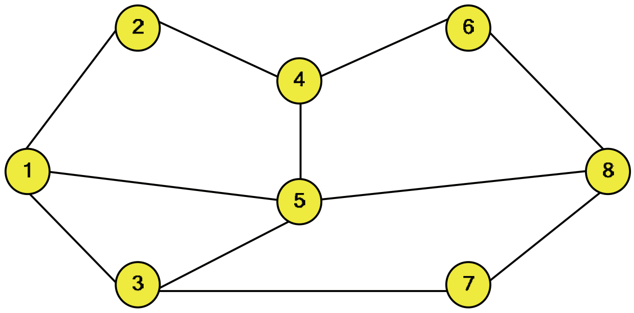

Fig 1. The optical WDM network physical topology

IV. Numerical Results

For the given physical network topology, the number of available wavelengths W and the given traffic demand matrix D we can obtain the optimal solution of the MaxRWA problem by solving the ILP formulation given in [6]. The optimal solution for physical routes and asssigned wavelengths of the established lightpaths are given in Table 1 for the case when W=4. We can see that all of the 40 requested lightpaths can be established before the link failure is occured. The required computing (CPU) time to obtain the optimal solution was 740 seconds with the processor on 1.66 GHz with 512MB of RAM.

Now, we will assume that the traffic is carried over the obtained logical topology and that the failure is occured on the physical link between nodes 3 and 5. The optimal solution of the RWA problem after the link failure is also given in the Table I. We can see that the total number of established lightpaths equals now 37. The CPU time required to obtain the optimal solution is nearly same as in the case before the link failure. Therefore, the time need to recover the network after the link failure would not be admissible if this approach is used.

However, if the reconfiguration approach is performed based on the BCO metaheuristic, the total number of (re)established lightpaths is same as in the case of optimal (ILP) solution, but with the considerably reduced computation time of only 4 CPU seconds. As a result, traffic disruption in network could not take for a long period of time in the case of the BCO reconfiguration.

The results for the lightpaths' routes and assigned wavelengths obtained by using the BCO reconfiguration approach are given in the Table II. It can be seen that the total number of established lightpaths equals 37 which is the same as in the case of optimal (ILP) solution.

TABLE I. OPTIMAL RWA SOLUTIONS BEFORE AND AFTER THE FAILURE ON THE PHYSICAL LINK (3,5)

#	Node pair	BEFORE LINK FAILURE		AFTER LINK FAILURE	
		Route	Wave-length	Route	Wave-length
1	(2,1)	2→1	λ1	2→1	λ4
2	(3,1)	3→1	λ4	3→1	λ3
3	(4,1)	4→2→1	λ3	4→2→1	λ2
4	(6,1)	6→4→5→1	λ4	6→4→5→1	λ2
5	(7,1)	7→3→5→1	λ2	7→3→1	λ1
6	(8,1)	8→5→1	λ1	8→5→1	λ3
7	(1,2)	1→2	λ4	1→2	λ1
8	(3,2)	3→1→2	λ2	3→1→2	λ2
9	(5,2)	5→4→2	λ4	5→4→2	λ3
10	(8,2)	8→6→4→2	λ2	8→6→4→2	λ4
11	(1,3)	1→3	λ1	1→3	λ2
12	(2,3)	2→4→5→3	λ1	2→1→3	λ3
13	(4,3)	4→5→3	λ2	4→5→8→7→3	λ4
14	(5,3)	5→3	λ4	5→1→3	λ4
15	(6,3)	6→8→5→3	λ3	6→8→7→3	λ3
16	(7,3)	7→3	λ4	7→3	λ2
17	(2,4)	2→4	λ2	2→4	λ2
18	(3,4)	3→5→4	λ1	3→1→5→4	λ4
19	(6,4)	6→4	λ3	6→4	λ3
20	(7,4)	7→3→5→4	λ3	7→8→6→4	λ1
21	(8,4)	8→6→4	λ1	8→5→4	λ2
22	(1,5)	1→5	λ4	1→5	λ3
23	(4,5)	4→5	λ3	4→5	λ3
24	(7,5)	7→8→5	λ4	7→8→5	λ4
25	(8,5)	8→5	λ2	8→5	λ1
26	(1,6)	1→2→4→6	λ3	1→2→4→6	λ4
27	(2,6)	2→4→6	λ4	2→4→6	λ3
28	(3,6)	3→5→8→6	λ4	3→7→8→6	λ3
29	(4,6)	4→6	λ2	4→6	λ2
30	(7,6)	7→8→6	λ3	7→8→6	λ2
31	(2,7)	2→1→3→7	λ4	/	/
32	(3,7)	3→1→5→8→7	λ3	3→7	λ2
33	(5,7)	5→1→3→7	λ3	5→1→3→7	λ1
34	(6,7)	6→8→7	λ2	6→8→7	λ2
35	(8,7)	8→7	λ1	8→7	λ1
36	(1,8)	1→3→7→8	λ2	1→5→8	λ2
37	(2,8)	2→1→5→8	λ2	2→4→6→8	λ1
38	(3,8)	3→7→8	λ1	/	/
39	(4,8)	4→6→8	λ1	4→2→1→5→8	λ1
40	(7,8)	7→3→1→5→8	λ1	/	/

TABLE II. RWA SOLUTION BASED ON THE BEE COLONY OPTIMZATION METAHEURISTIC

#	Node pair	Route	Wave-length
1	(2,1)	2→1	λ2
2	(3,1)	3→1	λ1
3	(4,1)	4→5→1	λ4
4	(6,1)	6→4→2→1	λ1
5	(7,1)	7→3→1	λ2
6	(8,1)	8→5→1	λ1
7	(1,2)	1→2	λ2
8	(3,2)	3→1→2	λ3
9	(5,2)	5→4→2	λ3
10	(8,2)	8→6→4→2	λ4
11	(1,3)	1→3	λ1
12	(2,3)	2→1→3	λ4
13	(4,3)	4→6→8→7→3	λ4
14	(5,3)	5→1→3	λ2
15	(6,3)	6→8→7→3	λ3
16	(7,3)	7→3	λ1
17	(2,4)	2→4	λ4
18	(3,4)	3→1→5→4	λ4
19	(6,4)	6→4	λ2
20	(7,4)	7→8→6→4	λ3
21	(8,4)	8→5→4	λ2
22	(1,5)	1→5	λ3
23	(4,5)	4→5	λ2
24	(7,5)	/	/
25	(8,5)	8→5	λ3
26	(1,6)	1→5→8→6	λ2
27	(2,6)	2→4→6	λ3
28	(3,6)	3→7→8→6	λ1
29	(4,6)	4→6	λ2
30	(7,6)	/	/
31	(2,7)	2→1→3→7	λ3
32	(3,7)	3→7	λ4
33	(5,7)	/	/
34	(6,7)	6→8→7	λ2
35	(8,7)	8→7	λ1
36	(1,8)	1→5→8	λ1
37	(2,8)	2→4→6→8	λ1
38	(3,8)	3→7→8	λ2
39	(4,8)	4→5→8	λ3
40	(7,8)	7→8	λ4

Now, we will compare our BCO reconfiguration approach with the commonly used rerouting approach in the case of link failures. We assume the same network scenario as described in the case of reconfiguration approach.

In the rerouting approach, we assumed that a link-disjoint physical route could be found for each node pair after the failure on any link is occured. The occupied wavelenghts over the fiber links after the physical link (3,5) is failed are shown in the Figure 2. These graphs are drawn based on the optimal RWA solution given in the Table 1 (before the link failure) with releasing the resources which were occupied by disrupted lightpaths.

It can be seen from the Table I that the total of 8 lightpaths will be disrupted if the physical link between nodes 3 and 5 is failed. Those are the lightpaths labeled with the ordinary numbers: 5, 12, 13, 14, 15, 18, 20 and 28. After the link failure is occured, these lightpaths are tried to be rerouted. However, by performing the rerouting algorithm based on the link disjoint paths, it can be shown that no one of the disrupted lightpath can be rerouted due to lack of avilable resources (wavelengths) in given network. Consequently, the number of disrupted lightpaths when applying the rerouting approach is 8, while with the BCO reconfiguration approach is reduced to 3 with the same available resources in network. It means that the rerouting approach gives worse performances compared to the BCO-based reconfiguration approach according to the link failure recovery problem.

V. Conclusion

The Bee Colony Optimization (BCO) represents the new metaheuristic capable to solve difficult combinatorial optimization problems. In this paper, the BCO is used to solve the optical WDM network recovery problem when the physical link failure occurs in a network. The results obtained through performed simulation of the link failure event in a given optical network show that the BCO reconfiguration approach could give better performances compared to the rerouting approach.

If the short service disruption time is tolerable than the BCO reconfiguration can be usefull approach for fast network recovery in a case of link failure until the new logical network topology is fully reconfigured.

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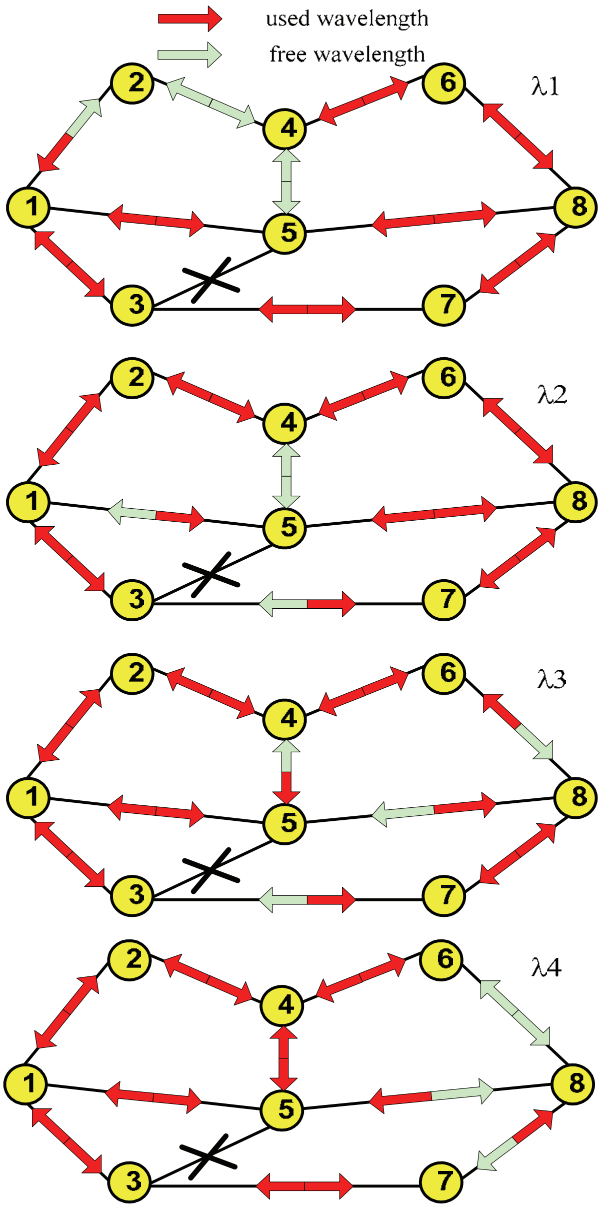

Fig.2 Available wavelengths after the failure on link (3,5)

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