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Observations on using Genetic Algorithms for Routing and Wavelength-Assignment (RWA) in All-optical networks

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Abstract

All-optical networks based on wavelength division multiplexing (WDM) have emerged as a promising technology for network operators to respond to an increased demand for broadband service. All-optical networks consist of optical fiber links and nodes. Each node has a dynamically configurable optical switch or router, which supports wavelength based switching or routing. Configuring these optical devices across the network enables one to establish all-optical connections, or *lightpaths,* between source and destination nodes.

In order to establish a lightpath, the network needs to decide on the route and the wavelength(s) for the lightpath. Given a set of connections, the problem of setting up lightpaths by routing and assigning a wavelength to each connection is called the Routing and Wavelength Allocation (RWA) problem. There are two variations of the problem: static and dynamic. In the static case the set of desired connections is known beforehand; in the dynamic case the connection requests arrive based on some stochastic process. The RWA problem can be simplified by decoupling it in four subproblems: the topology subproblem, the lightpath routing subproblem, the wavelength allocation subproblem and traffic routing subproblem.

All-optical WDM networks are characterized by multiple metrics (hop-count, cost, delay), but generally routing protocols only optimize one metric, using some variant of shortest path algorithms (e.g., the Dijkstra, All-pairs and Bellman-Ford algorithms). The multicriteria RWA problem has been solved combining the relevant metrics or objective functions. This is achieved by defining integrated link cost functions (which embed the different metrics) or using a single cost objective function defined as a weighted sum of objective functions. This paper outlines the application of GA to solve a RAW problem. We have proposed a modified genetic algorithm with reference to the basic model proposed by Zhong Pan. The modifications proposed are change of fitness function by adding a new parameter *hopcount* and a two-point crossover operation is used instead of single-point crossover. The performance of both the algorithms are studied with respect to the time taken for making routing decision, number of wavelengths required and cost of the requested lightpaths. The modified algorithm performed better than the existing algorithm with respect to the time and cost parameters on standard networks such as ARPANET, and NSFNET. It has been observed that the proposed modified Genetic algorithm performed better than the existing algorithm with respect to the time and cost parameters.

1. Introduction

The wavelength division multiplexing (WDM) is a promising technology for future all-optical networks [1]. In WDM several optical signals using different wavelengths share same fiber. The capacity of such fiber links can be huge, even terabits per second. The physical limitations of the optical medium and the cost and complexity of optical switching need to be accounted for in this design. A particularly important consideration in this context is the wavelength number associated with an optical link. This is the number of separate wavelengths that can be supported in that link. The network has wavelength continuous (WC) network where the same wavelength must be used throughout the light path.

The optical signal on the fiber must be converted into an electronic signal, processed at low electronic speeds and then converted back to optical signals for transmission over optical fiber. Apart from slowing the network down, the electro-optic conversion needed to facilitate electronic processing is also expensive. The obvious solution to this problem is to build networks in which the signals are processed in the optical domain. Such networks are called *all-optical networks* [6].

The routing in network nodes is based on wavelengths of incoming signals. The routing and wavelength allocation (RWA) problem in WDM networks consists of choosing a route and a wavelength for each connection so that no two connections using the same wavelength shares the same fiber.

In this paper we have simulated the two variants of Genetic algorithm to solve RWA problem in all-optical networks with static loading. During the actual operation of the network, the traffic load offered to the network and the active source-destination node pairs may change dynamically. In this paper, we intend to study some of the important aspects of taking the routing decision with less time with less cost in a WDM network and propose algorithms that can be used to handle routing and wavelength allocation with less number of wavelengths.

2. Routing and Wavelength Allocation (RWA) Problem

A unique feature of optical WDM networks is the tight coupling between routing and wavelength selection. Selecting a path of physical links between the source and destination edge nodes, and reserving a particular wavelength on each of these links for the lightpath implement a lightpath. Thus, in establishing an optical connection we must deal with both routing (selecting a suitable path) and wavelength allocation (allocating an available wavelength for the connection). The resulting problem is referred to as the routing and wavelength allocation (RWA) problem.[2]

The additional complexity arises from the fact that routing and wavelength allocation are subject to the following two constraints: Wavelength continuity constraint and Distinct wavelength constraint.

The different variants of the problem, however, can be classified under one of two broad versions: a *static RWA*, whereby the traffic requirements are known in advance, and a *dynamic RWA*, in which a sequence of lightpath requests arrive in some random fashion. The design of static RWA problem in all-optical networks can be logically decomposed into four subproblems.

1. **Topology Subproblem:** Determine the logical topology to be imposed on the physical topology, that is, determine the lightpaths in terms of their source and destination edge nodes.
2. **Lightpath Routing Subproblem:** Determine the physical links, which each lightpath consists of, that is, route the lightpaths over the physical topology.
3. **Wavelength Allocation Subproblem:** Allot a wavelength to each lightpath in the logical topology so that wavelength restrictions are obeyed for each physical link.
4. **Traffic Routing Subproblem:** Route packet traffic between source and destination edge nodes over the logical topology obtained.

In this thesis, second and third subproblems are implemented.

3. Mathematical model of RWA Problem

An ILP formulation of the RWA problem for single fiber networks assuming neither a special topology nor wavelength conversion i.e., the wavelength continuity constraint is satisfied, which is derived from [5].

The network is modeled as an undirected graph G = (V,E) consisting of a set of V of nodes and a set of E of links where |V| = N and |E| = M. Each fiber link can support a set of W wavelengths, where |W| = F.

Let P denote the set of paths in the network G.

P(e) (respectively P(s,d)) denote subset of paths in G that use link $e \in E$ (respectively join nodes $s \in V$ and $d \in V$)

and r_{sd} denote the number requests between nodes $s \in V$ and $d \in V$.

A lightpath request between s and d is realized by finding a physical path $p \in P(s,d)$ and a wavelength $\omega \in W$ that is assigned to every link on p; which ensures wavelength continuity constraint. The pair (p, ω) is called a lightpath. To avoid wavelength clash, two lightpaths with the same wavelength cannot share a common fiber. The goal is to minimize the number of wavelength and maximize the number of lightpath requests realized.

Let x(p, ω) denote the number of lightpaths successfully routed over physical path $p \in P$ and assigned wavelength $\omega \in W$. The RWA problem can be cast as ILP as follows:

$$\max \sum_{\omega \in W} \sum_{p \in P} x(p,\omega)$$

subject to :

1. Distinct wavelength constraint $\sum_{p = P(e)} x(p,\omega) \le 1, \forall e, \omega$

2. Number of wavelengths established does not exceed the number of requests

$$\sum_{\omega \in W} \sum_{p \in P(s,d)} x(p,\omega) \le rsd, \forall s,d \qquad \text{where } x(p,\omega) \ge 0, \quad \text{integer}, \forall p,\omega$$

The RWA problem is NP-Complete for single fiber networks since node coloring problem can be reduced to wavelength allocation [4,5].

Let W_e denote the set of wavelengths supported by the fibers deployed on link e. Since wavelength conversion is not present, the set of wavelengths supported by some path p would be $Wp = \bigcap_{e \in p} We$.

Therefore, the set of wavelengths W considered in our formulation can be thought of as being $W = \bigcup_{p \in P} Wp$. This results into the requirement of minimization of the links that are intersecting each other in different paths $p \in P$ of requests.

4. Genetic Algorithm for RWA Problem

The main objective of this RWA problem is to find the route for each lightpath (s_i,d_i): $n_{i0}, n_{i1}, \cdots n_{ih_i}$ to minimized the number of wavelengths needed, where $n_{i0} = s_i$, $n_{ih_i} = d_i$, n_{ij}, $j \neq 0, h_i$ are the same intermediate nodes, and also include the secondary targets to minimize the total cost and to minimize the maximum cost of a lightpath [3]. To achieve this, the following **assumptions** are made:

1. Network is static and circuit switched.
2. The wavelength continuity constraint is satisfied, as there is NWC.
3. Both fiber links and lightpaths are bi-directional.
4. There is no limit on the number of available wavelengths a fiber can carry.

Different **parameters** used in this algorithm are:

i) pop : The number of chromosomes in a generation. A large pop is necessary to maintain a good diversity.
ii) gen_max : The maximum number of generations to run.
iii) mrate : The probability of performing mutation operation on the new generation chromosome.
iv) crate: The probability a selected new generation chromosome undergoes crossover.
v) mratio : The percentage of lightpaths in a selected chromosome will be modified in a mutation operation.
vi) cratio : The percentage of lightpaths in a selected chromosome will be modified in a crossover operation.

Chromosome structure – The chromosome is a group of vectors P. Each vector $P_i = [n_{i0}, n_{i1}, \cdots n_{ih_i}]$ is the route of the lightpath (s_i,d_i). So each chromosome is a solution is a solution to the problem. In the implementation p_i's are 0-padded to length N so that a chromosome can be effectively represented by a matrix. The structure represented with a string of numbers of nodes in the network G instead binary strings to avoid the difficulty implementation of operations.

Selection of fitness function

Fitness function can be considered as the target function to be maximized. For the routing problem, the fitness function can be defined as:

$$y = 1 - 0.9\frac{overlaps}{N_i} - 0.08\frac{total\cos t}{N_i(N_i-1)\max link\cos t} - 0.02\frac{\max\ path\cos t}{(N-1)\max link\cos t}$$

where N_i is the number of lightpaths

N is the number of nodes

maxlinkcost is the maximum cost of a fiber link in the network

The fitness function is composed of three main items, each is divided by its maximum possible value, and each describes a metric that needs to be minimized:

1. overlaps : It can be observed that the maximum number of overlapping lightpaths in a same fiber link is just the number of wavelengths required to establish all the lightpaths.
2. totalcost : The total cost of all the fiber links used in all the lightpaths. It is desired to minimize this value.
3. maxpathcost : The maximum cost of a lightpath. It is also desired to minimize this value, but it is not so important as overlaps and totalcost.

4.1 Existing Genetic Algorithm (GA-1)

The basic genetic algorithm used in this thesis is as follows:

Step1: Obtain the costs of links in network G.

Step2: Generate the first generation (initial) population.

2.1 For every lightpath (s_i,d_i), employ Dijkstra's algorithm to find the minimum-cost path p_i. All the p_i's form the first chromosome.

2.2 For each fiber link (n_{ij},$n_{i(j+1)}$) in every p_i, cut only one link at a time (disturbance), and find the minimum-cost paths to form a new chromosome as in step 1 at each time. Stop when the pop is reached. Where pop is the population strength.

2.3 If pop is not reached after all the disturbances, copy the existing ones multiple times until enough chromosomes are generated.

Step 3: Evolve the Fitness using fitness function

$$y = 1 - 0.9\frac{overlaps}{N_l} - 0.08\frac{total \cos t}{N_l(i-1)\max link \cos t} - 0.02\frac{\max path \cos t}{(N-1)\max link \cos t}$$

where N_l is number of links in the lightpath

Step 4: Selection of next generation population

The chromosomes of the next generation are selected from the current population by a spinning roulette-wheel method.

4.1 The fitness function values of the current population are normalized as:

$$fitness_i = \frac{fitness_i - \min(fitness_i)}{\max(fitness_i) - \min(fitness_i)}$$

The proposed normalization technique has two advantages:

i) The range of fitness function can be negative. But it aims to be the larger value of the fitness.

ii) When the difference between the fitness values of good ones and bad ones in the population is less, it is difficult to identify. So normalization becomes useful in such case.

4.2 The probability of the selection $prob_i$ for each chromosome is defined as its fitness divided by the total fitness. $prob_i = \frac{fitness_i}{\sum_i fitness_i}$

4.3 Calculate a cumulative probability q_i for each chromosome:

$$q_i = \sum_{j=1}^{i} prob_i$$

4.4 Spin the roulette wheel pop times. Each time select a single chromosome for the next generation. Specifically for each spin

i) Generate a random float number r in [0,1].

ii) If $r < q$, then select the first chromosome; otherwise the i^{th} chromosome such that $q_{i-1} < r < q_i$.

In this is method of selection; the same chromosomes can be selected more than once. But is based on the criterion that all good ones are selected many times causes the bad ones die off.

Step 5: Application of Mutation operator

A selected generation, with probability mrate a chromosome is mutated. The mutation operation defined in this algorithm is:

5.1 According to mratio calculate the number of lightpaths that will be modified in this operation. Pick these lightpaths randomly.

5.2 For each such lightpath $P_i = [n_{i0}, n_{i1}, \cdots n_{ih_i}]$, randomly pick two nodes n_{ij} and n_{ik} (assume $j < k$). Cut all the fiber links that appear between n_{ij} and n_{ik}. Remove all the nodes n_{ij} such that $l < j$ or $l > k$. Then find the minimum-cost path from n_{ij} to n_{ik} and replace the corresponding portion in p_i using the new path.Deleting a node is to cut all the fiber links connected to that node. This is to prevent revisiting a node in the same lightpath.

Step 6: Application of crossover operator

A selected next generation, with probability crate a chromosome is crossovered with another randomly picked chromosome. Crossover algorithm is:

6.1 According to cratio calculate the number of lightpaths that will be modified in this operation. Pick these lightpaths randomly.

6.2 Exchange the picked lightpaths between the two chromosomes.

4.2 Modified Genetic Algorithm (GA-2)

In the above algorithm (GA-1), the following changes are proposed in order to increase its performance. The steps 3 and 6 above are changed as follows.

Step 3: Evolve the Fitness using fitness function

Taking one another parameter, hopcount, modifies the fitness function as

$$y = 1 - 0.9\frac{overlaps}{N_l} - 0.08\frac{total \cos t}{N_l(N-1)\max link \cos t} - 0.01\frac{\max path \cos t}{(N-1)\max link \cos t} - 0.01\frac{hopcount}{N-1}$$

The new parameter, hopcount can be defined as the number of hops taken by each lightpath.

Step 6: Application of two-point crossover operator

By keeping this in mind, a two-point crossover is used that enables the two routing of subpath and exchanges the subpath between them.

In the selected next generation, with probability crate a chromosome is crossover with another randomly picked chromosome. The crossover operation defined in this algorithm is:

6.1 According to cratio calculate the number of lightpaths that will be modified in this operation. Pick these lightpaths randomly.
6.2 Exchange the picked lightpaths between the two chromosomes.

By applying the above changes to the algorithm, the performance of the algorithm are increased in terms of time taken by the algorithm and the total cost of lightpaths have been considerably decreased. This makes the data transfer with more speed and less delay.

5. Experimental Results

The algorithms GA-1 and GA-2 are implemented and the results are obtained for ARPANET, and NSFNET. The results are obtained for different sets of lightpath requests. A sample of results obtained for ARPANET and NSFNET are presented in this section.

5.1 Simulation Results with ARPANET

From figure 1, it can be observed that the algorithms GA-1 and GA-2 take almost same time for executing the routing decision for less number lightpath requests. GA-2 is performing better than GA-1 when there are any number of lightpath requests are present for ARPANET.

From figure 2, it can be observed that the algorithms GA-1 and GA-2 take unstable costs of the paths for less number lightpath requests for ARPANET. The total cost of paths calculated under GA-2 is performing better than GA-1 when there are more number of lightpath requests are present.

For ten lightpaths (Source-Destination pairs) requests, the results are obtained as follows:

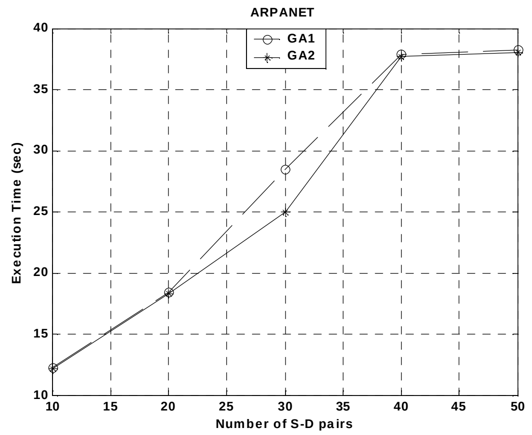


Figure1: Performance of GA-1 and GA-2 algorithms: Execution time of the routing Vs Number of S-D node pairs (lightpath requests)

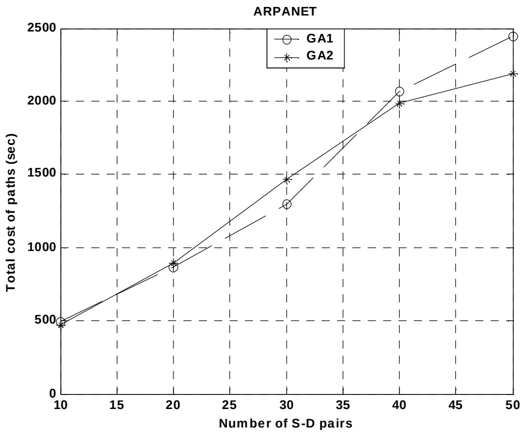
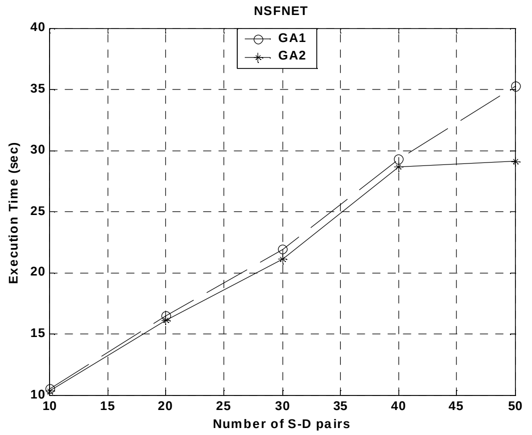


Figure 2: Performance of GA-1 and GA-2 algorithms: TotalCost of paths Vs Number of S-D node pairs (lightpath requests)

For GA-1	**For Modified GA (GA-2):**
Lightpath 10 to13: 10 19 20 17 13	Lightpath 10 to 13: 10 19 20 17 13
Lightpath 15 to 7: 15 16 19 10 7	Lightpath 15 to 7: 15 16 19 10 7
Lightpath 7 to 4: 7 3 1 2 5 4	Lightpath 7 to 4: 7 3 1 2 5 4
Lightpath 10 to 1: 10 7 3 1	Lightpath 10 to 1: 10 7 3 1
Lightpath 15 to 14: 15 14	Lightpath 15 to 14: 15 14
Lightpath 10 to 8: 10 8	Lightpath 10 to 8: 10 8
Lightpath 8 to 15: 8 12 18 16 15	Lightpath 8 to 15: 8 12 14 15
Lightpath 2 to 10: 2 4 11 9 10	Lightpath 2 to 10: 2 4 11 9 10
Lightpath 3 to 9: 3 8 9	Lightpath 3 to 9: 3 8 9
Lightpath 9 to 20: 9 8 12 14 20	Lightpath 9 to 20: 9 8 12 14 20
maximum fitness = 0.808289	maximum fitness = 0.807526
Number of wavelengths required = 2	Number of wavelengths required = 2
TotalCost = 490.000000	TotalCost = 468.000000
Maxpathcost = 101.000000	Maxpathcost = 96.000000
The algorithm took 12.200000 seconds to run.	The algorithm took 12.100000 seconds to run.

5.2 Simulation Results with NSFNET



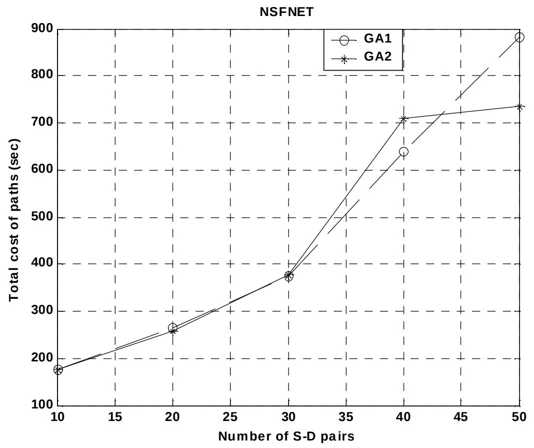


Figure3: Performance of GA-1 and GA-2 algorithms: Execution time of the routing Vs No of S-D node pairs	Figure 4: Performance of GA-1 and GA-2 algorithms: TotalCost of paths Vs No of S-D node pairs

From figure 3, it can be observed that the algorithms GA-1 and GA-2 take almost same time for executing the routing decision for less number lightpath requests. GA-2 is performing better than GA-1 when there are any number of lightpath requests are present. When there exists a large number of lightpath requests, GA-2 is performing considerably well for NSFNET.

From figure 4, it can be observed that the algorithms GA-1 and GA-2 take almost same totalcost of paths for less number lightpath requests. GA-2 is performing better than GA-1 when there are any number of lightpath requests are present. When there exists a large number of lightpath requests, GA-2 is performing considerably well for NSFNET when number of lightpath requests are 50.

Table 1 list out the simulation results in a nutshell. The genetic algorithms GA-1 and GA-2 are implemented and their results are obtained for three networks ARPANET, NSFNET and National Network. These results are carried out for different sets of lightpath requests.

For ten lightpaths (Source-Destination pairs) requests, the results are obtained as follows:

For GA-1

```
Lightpath 11 to 13:   11   15   14   13
Lightpath 13 to 7:    13    6    7
Lightpath 7 to 5:      7    4    5
Lightpath 12 to 15:   12    11    15
Lightpath 15 to 14:   15    14
Lightpath 14 to 8:    14     8
Lightpath 8 to 12:     8     9    10    11    12
Lightpath 2 to 10:     2     5    11    10
Lightpath 16 to 9:    16  12   4   7   1  3  10  9
Lightpath 9 to 2:      9     8    14    16     5   2
maximum fitness = 0.803901
Number of wavelengths required  = 2
TotalCost = 176.210000
Maxpathcost = 19.850000
The algorithm took 10.440000 seconds to run.
```

For Modified GA (GA-2):

```
Lightpath 11 to 13:  11  15  14  13
Lightpath 13 to 7:    13   6    7
Lightpath 7 to 5:      7    4    5
Lightpath 12 to 15:  12  11    15
Lightpath 15 to 14:  15  14
Lightpath 14 to 8:    14   8
Lightpath 8 to 11:    8   7   6  13  14  16   5  11
Lightpath 2 to 10:    2  12   11  10
Lightpath 16 to 9:   16  14   8   9
Lightpath 9 to 2:      9  10  11   5   2
maximum fitness = 0.804312
Number of wavelengths required  = 2
TotalCost = 162.870000
Maxpathcost = 42.580000
The algorithm took 10.340000 seconds to run.
```

No. of Requests	**Parameters**	**ARPANET**		**NSFNET**	
		GA-1	**GA-2**	**GA-1**	**GA-2**
10	No. of Wavelengths	2	2	2	2
	Execution Time	12.2	12.16	10.44	10.34
	Total cost	490	468	176.21	162.87
20	No. of Wavelengths	4	4	4	4
	Execution Time	18.4	18.26	16.42	16.06
	Total cost	868	896	265.29	258.31
30	No. of Wavelengths	6	6	5	5
	Execution Time	28.5	24.99	21.91	21.12

	Total cost	1294	1496	374.98	376.99
40	No. of Wavelengths	8	8	8	8
	Execution Time	37.89	37.67	29.22	28.67
	Total cost	2066	1985	639.93	709.43
50	No. of Wavelengths	10	10	9	9
	Execution Time	38.16	38.0	35.26	29.06
	Total cost	2443	2188	883.54	734.17

Table 1: Results obtained for ARPA, and NSF Networks for different sets of light-path requests

6. Conclusion

The RWA problem in all-optical WDM networks is solved using the proposed genetic algorithm that found to be successful in terms of cost of the light-paths requested and the time taken for routing decision making. The problem is analyzed and solved by considering the parameters: Number of wavelengths required, Cost of the light paths requested and Number of hops in each path. The performance of proposed algorithm has been compared with that of one proposed by Zhong Pan(2002)The performance of both the algorithms are studied with respect to the time taken for making routing decision, number of wavelengths required and cost of the requested lightpaths. The modified algorithm performed better than the existing algorithm with respect to the time and cost parameters. But its performance is same in terms of number of wavelengths.

7. References

[1] M.C. Sinclair, "*Minimum Cost Wavelength-Path Routing and Wavelength Allocation using a Genetic Algorithm/Heuristic Hybrid Approach",* IEEE Proceedings on Communications, February 1999.

[2] George N. Rouskas, "*Routing and Wavelength Assignment in Optical WDM Networks*", IEEE Journal on Selected Areas in Communications, 2001.

[3] Zhong Pan, "*Genetic Algorithm for Routing and Wavelength Assignment Problem in All-optical Networks*", a technical report submitted to the Department of Electrical and Computer Engineering, University of California, Davis, 2002.

[4] Hao Qin, Zengji Liu, Shi Zhang and Aijun Wen, "*Routing and Wavelength Assignment based on Genetic Algorithm*", IEEE Communication Letters, October 2002.

[5] R. Ramaswami, and K.N. Sivarajan, "*Routing and Wavelength Assignment in All Optical Networks,"* IEEE Journal on Selected Areas in Communications, June 1996.

[6] C. Sivaramamurthy and Mohan Guruswamy, “WDM Optical Networks – Concepts Design and Algorithms”, text book, Prentice-Hall PTI, 2002, ISBN 0-13-060637-5.