Routing and Wavelength Assignment Based on Variable-Rate Genetic Algorithm

Jun He, Deming Liu, Wei Li, Chunyong Yang
Department of Optoelectronic Engineering
Huazhong University of Science and Technology
Wuhan, P.R. China
hejun_2k@hotmail.com

Abstract: Appropriate routing and wavelength assignment (RWA) algorithms are the two key factors in improving the blocking performance in wavelength-routed all-optical networks [3]. Given a static channel demand, the problem of routing and wavelength assignment (RWA) in such networks has to be solved. Due to the restricted number of wavelengths available on each link it is desirable to get a solution of the RWA problem, in which the bad edge in wavelength relationship graph is minimized. This optimization problem belongs to the class of NP-complete problems. In this paper, we propose an optimal path routing principle and improve the methods in [1][2] by enhancing genetic algorithm and present our new powerful method for the approximate solution of the RWA problems. This new approach is based on variable mutation and crossover rates of genetic algorithm. We name it VMCR-GA. The efficiency of enhanced novel algorithm is demonstrated by the numerical results obtained for 10-node CERNET, 14-node NSFNET and 19-node EON and compared with the normal genetic algorithm.

Keywords: Routing and wavelength assignment (RWA), genetic algorithm, wavelength-division multiplexing (WDM), wavelength routing, all-optical networks

I. Introduction

Wavelength Division Multiplexing (WDM) networks using wavelength routing have been popular for the need of wide bandwidth, high-speed transmission in all-optical networks. In a wavelength routing optical networks (WRON) one wavelength is dedicated to each channel between different nodes of the network and a number of channels referred to as wavelength channels (WCHs), are transmitted on a single fiber by using different wavelengths.

In the paper it is assumed that the available number of wavelengths on a single fiber is constrained. Our optimal RWA objective is to establish the maximum number of given connections or minimum number of bad edges in the wavelength relationship graph (WRG).

In order to balance the capacities of optical links in the network, optimal routing is considered. In this case a path is not necessarily the shortest; the paths are chosen from a set of paths (the shortest path, the second shortest path, etc.).

In previous works, many heuristic techniques are employed in solving the problem, which is proved to be an NP-complete. The paper improves the normal genetic algorithm (GA) presented in

[2][4] by introducing variable mutation and crossover rates (VMCR) and presents an application of VMCR-GA to RWA in WDM networks.

In this paper, we firstly propose RWA problem description, which is explained by a simple five-node network. In section III, we propose the VMCR-GA. Then we analyze the performance of CRENET and demonstrate the efficiency of enhanced novel algorithm by the numerical results obtained for 10-node CERNET, 14-node NSFNET and 19-node EON in Section IV. Finally, we provide our conclusions in section V.

II. RWA Problem description

For simplicity reasons, we divide RWA problem into routing problem and wavelength assignment problem. Firstly, we propose an optimal algorithm to solve routing problem. Secondly, we assign wavelengths for every WCH. Then we adjust routing table by WRG and get an optimal result.

A. Routing and Wavelength Assignment Algorithm

In order to describe RWA problem, definitions of a network model are given by using graph theoretic terminology. We model the network using a directed graph $G=(V,L)$, where V is the set of vertices representing the network nodes and L is the set of directed edges representing the unidirectional fiber links in the network. The directed link from node i to node j is represented by l_{ij}. The number of available wavelength channels (W_λ) is constrained.

We consider optimal routing to balance the capacities of optical links in the network. In this case, a path is not necessarily the shortest, such as Dijkstra's shortest path first algorithm; the paths are chosen from a set of paths (the shortest path, the second shortest path, etc.).

We consider wavelength assignment problem by converting it to graph coloring problem. We create a wavelength relationship graph (WRG), in which each node represents a wavelength channel to which a wavelength should be assigned. Two nodes, i.e. wavelength channels, in the WRG are connected by direct branch if they are not independent and disjoint. Not that link in the WRG represents the fact that either space or time conflict is possible between the two WCHs.

B. An Example for RWA procedure

RWA procedure will be explained on a simple five-node network, as shown in Figure 1.

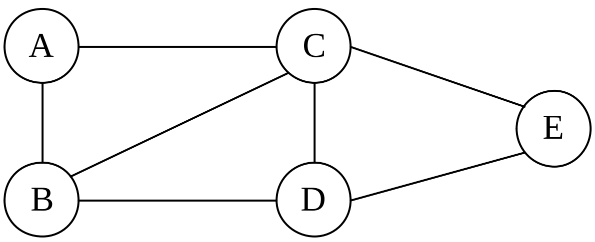

Figure 1. An optical network with 5 nodes

For simplicity, it is assumed that for each connection only one wavelength channel is required. Then we can get its routing table by Dijkstra algorithm [6, p.273], as shown in Table I.

TABLE I. SHORTEST PATH INFORMATION FOR NETWORK SHOWN IN FIG. 1

From A to B: $A \longrightarrow B$	From B to D: $B \longrightarrow D$
From A to C: $A \longrightarrow C$	From B to E: $B \longrightarrow C \longrightarrow E$
From A to D: $A \longrightarrow B \longrightarrow D$	From C to D: $C \longrightarrow D$
From A to E: $A \longrightarrow C \longrightarrow E$	From C to E: $C \longrightarrow E$
From B to C: $B \longrightarrow C$	From D to E: $D \longrightarrow E$

For the example network, WRG is composed of 10 nodes, which is shown in Figure 2.

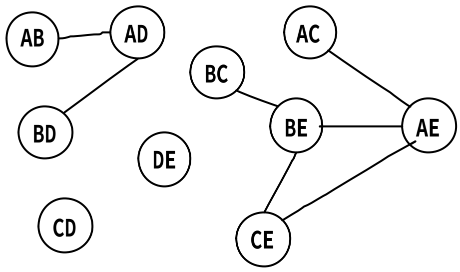

Figure 2 WRG of example network

Now we can adjust routing table by two criteria:

1) If WRG has separate nodes, we should consider connect them into other nodes.
2) If a node has the most connecting degree in the network, we should consider disconnect some links by selecting other routing path.

According above criteria, we can revise figure 2 into figure 3,

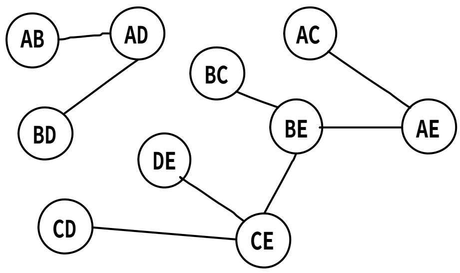

Figure 3 Revised WRG of example network

We can find that it need 3 wavelengths in Fig 2 and it need 2 wavelengths in Fig 3. If only 2 wavelengths in Fig 2, it will have 1 bad edge in the WRG.

III. Variable Mutation & Crossover Rates of Genetic Algorithm

A. Genetic Algorithm

In this section we shortly present the basics of genetic algorithms in general. Simultaneously we show how such a genetic algorithm can be used for the special problem of RWA.

In order to apply a genetic algorithm, generally a suitable encoding of possible solutions in a vector representation is needed. In our special case we use binary representation in encoding the possible solution. An example of encoded solution is presented in Table II.

TABLE II. AN ENCODEING STRUCTURE FOR EXAMPLE OF THE NETWORK IN FIG 1

λ	1	1	0	0	0	1	1	0	1	0
path pair	A,B	A,C	A,D	A,E	B,C	B,D	B,E	C,D	C,E	D,E

Using this special kind of coding, we first produce a so-called initial population by randomly generating a suited number of vectors in the described manner. Furthermore it is necessary to evaluate the quality of these solution vectors. Therefore we apply the total number of bad edge in WRG to fitness function of genetic algorithm. Now many iterations of the genetic algorithm are executed in order to improve the quality of the given solution vectors (individuals), which is shown in Fig. 4.

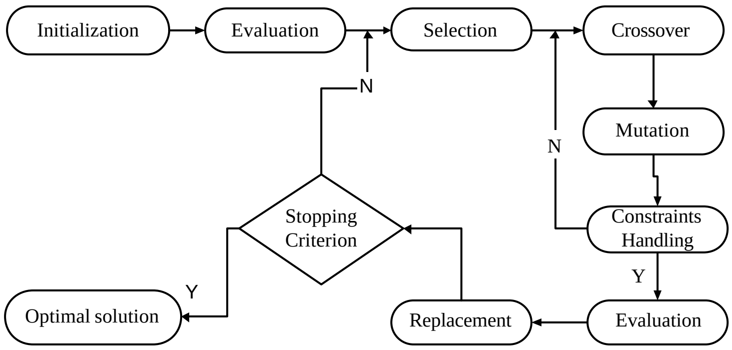

Figure 4. Genetic Algorithm

Where the main structure of such a genetic iteration is illustrated. At the beginning of each iteration, some vectors of high quality are selected to produce new, hopefully better, solutions. After this selection there follow two different methods to produce new vectors. The first one is called crossover and explores the diversity in the individual's bits. The production of new vectors by crossover consists of the combination of two (possibly mutated) vectors contained in the old population. We use the uniform crossover operator by which a single child is created from two parents by copying each bit value from either parent [7, p.49], the probability of which is given in the parameter setting.

The second method to create new solution vectors is called mutation and changes the selected children bits randomly, which is applied after the crossover on each child independently. This special variant of the mutation procedure aims to additionally improve the convergence speed and avoid converging prematurely to some sub-optimal solutions.

After the numbers of children arrive at the population of the generation in genetic algorithm, we will construct the next population by substituting the worse solution vectors of parents by the new ones.

In the present study, we have simply used a stopping criterion based on the number of generations. Our algorithm step stops when the generation counter exceeds the preset maximum number of generations.

B. Variable Mutation & Crossover Rates of Genetic Algorithm

According to W_λ, each wavelength channel is represented in chromosome by M bits, where $M = \lceil \log_2 W_l \rceil$. The total string length is obtained by summing up the number of required bits for each WCH. Since 2 wavelengths per fiber and optimal path routing are assumed in the example, 1 bit is used to represent each WCH, resulting in the chromosome size of 10 bits.

If the optical network has many nodes more than 10, the chromosome size is very large. The speed of finding optimal result is slow. In order to speed up the process, we introduce variable mutation and crossover rates of genetic algorithm.

In genetic algorithm, mutation method aims to additionally improve the convergence speed and avoid converging prematurely to some sub-optimal solutions; the crossover method explores the diversity in the individual's bits.

When we find that convergence speed slows down, we will increase the value of mutation rate. When we find that the diversity of generation is small, we will increase the value of crossover rate. By these two ways, we improve the efficiency of genetic algorithm.

IV. Performance Evaluation

In this section we show 10-node CERNET, 14-node NSFNET and 19-node EON [5] and compared with the normal genetic algorithm.

We first consider CERNET, as shown in Fig. 5.

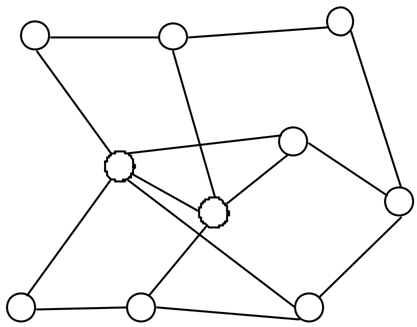

Figure 5. 10-node CERNET (China Education and Research Network)

Assuming every node connects other nodes, it results in the total of 45 WCHs for the whole network. We assume $\lambda = 7$ for the number of wavelengths on each link in Fig. 5.

The parameters of the applied GA are shown in Table III. The chromosome size is 135.

In VMCR-GA, variable mutation (VM) and crossover (VC) rates can adjust original mutation and crossover value according to the difference between children and parents generations.

For example, we will increase mutation value (MV) by adding (VMR X MV) if GA finds that convergence speed slows down (when

$$\left| \left(\sum \frac{Children}{Parents} \right)_{NGeneration} - \left(\sum \frac{Children}{Parents} \right)_{MGeneration} \right| \leq C \text{).}$$

The same operation runs for crossover value by adding (VCR X MV) when GA finds that children and parents are almost the same (when $\left|\sum Children - \sum parents\right| \le C$).

TABLE III. NORMAL GA VS VMCR- GA PARAMETERS

Normal Genetic Algorithm	VMCR-GA
Population size = 50	Population size = 50
Probability of crossover = 0.6	Probability of crossover = 0.6
Probability of mutation = 0.05	Probability of mutation = 0.05
Maximum number of generations = 5000	Maximum number of generations = 2000
Variable Mutaion Rate = 0	Variable Mutaion Rate = 0.2
Variable Crossover Rate = 0	Variable Crossover Rate = 0.1

The results are shown in Fig. 6 and Fig. 7.

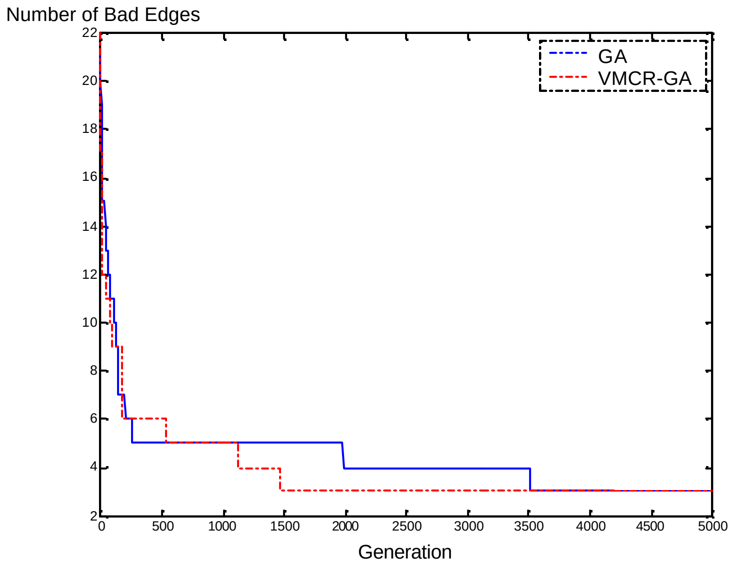

Figure 6 GA vs VMCR-GA by Shortest Path Routing Algorithm

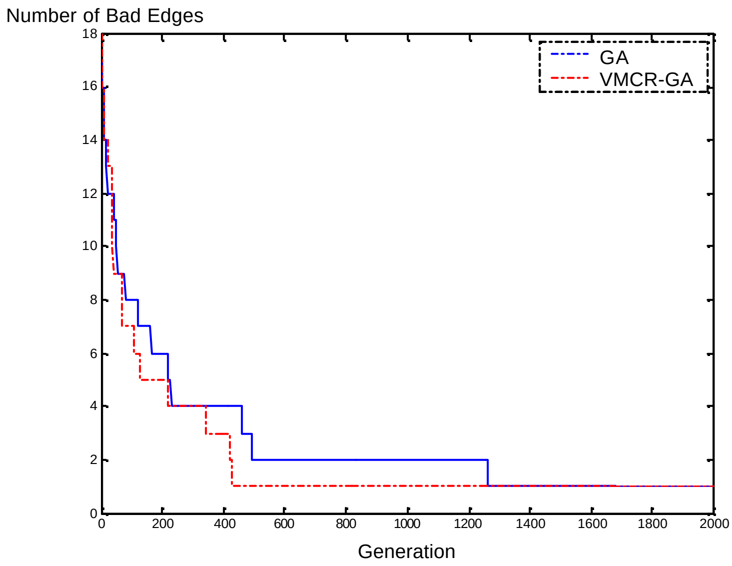

Figure 7 GA vs VMCR-GA by using Optimal Path Routing Algorithm

Compared Fig. 6 with Fig. 7, we can find that bad edges in WRG is decreased from 3 to 1 when $\lambda=7$. As shown in Fig. 6 and Fig. 7, we can find that VCMR-GA can greatly enhance the performance of GA, decreasing the number of the generation from 3500 to 1400 or 1300 to 420.

The networks topology of 14-node NSFNET and 19-node EON is shown in Fig.8 and Fig. 9.

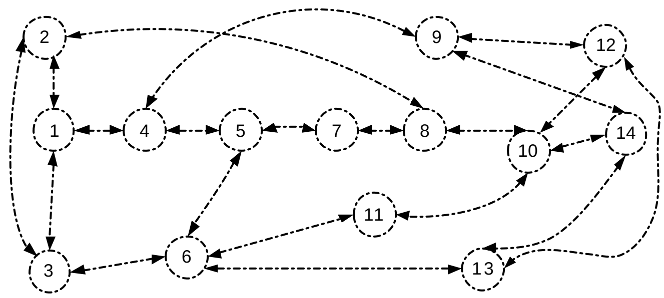

Figure 8. 14-node NSFNET network

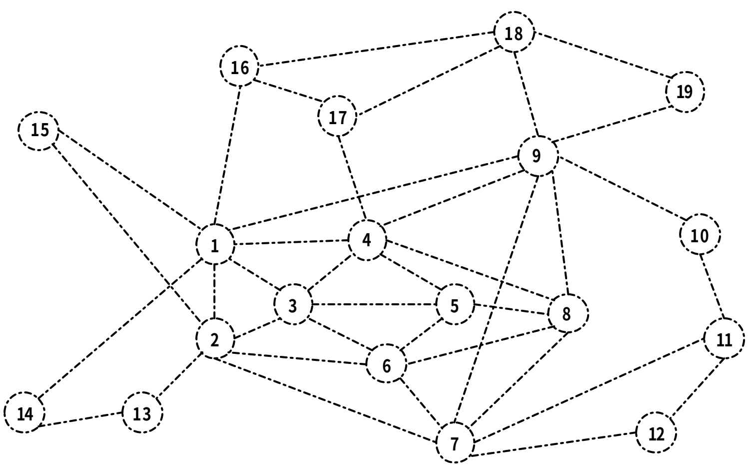

Figure 9. 19-node European Optical Network (EON)

The whole simulation results are shown in Table IV. In Table IV, λ is the number of wavelengths in networks; NN means the number of nodes in WRG, equal to W_λ; NE means the number of edges in the WRG. NG means the number of generation in GA process. NBE means the number of bad edges in the WRG.

TABLE IV. AN ENCODEING STRUCTURE FOR EXAMPLE OF THE NETWORK IN FIG 1

Network name	Routing algorithm	λ	NN of WRG	NE of WRG	NG of GA	NG of VMCR-GA	BNE of WRG
5-node network	SP	2	10	7	-	-	1
	Optimal	2	10	8	-	-	0
CERNET	SP	7	45	211	3500	1400	3
	Optimal	7	45	183	1300	420	1
NSFNET	SP	13	78	801	15500	6400	4
	Optimal	13	78	714	10100	3100	1
EON	SP	18	171	2306	25100	10500	13
	Optimal	18	171	2033	19000	6700	2

We can see from above table that the performance of GA has enhanced more than 100% wherever shortest path routing case or optimal path routing case.

V. Conclusion

In this paper, we presented an algorithm for optimally RWA problem in WRON. We also proposed an optimal path routing principle by using WRG, which has been compared with Dijkstra algorithm. Optimal path routing algorithm can improve the network performance obviously.

The purpose of our optimal method is to produce an optimal solution for a certain population of individuals in a limited number of generations. This method has been tested for 10-node CERNET, 14-node NSFNET and 19-node EON and compared with the normal genetic algorithm.

A major difference between normal GA and our optimal algorithm is in the speed for the optimal solution. Normal GA cannot self-adjust variables to accelerate the search speed. On the other hand, our optimal algorithm can change mutation and crossover rates by analyzing the generations.

In sum, our optimal algorithm for RWA problem is efficient to optimize the network and minimizes the number of bad edges in the all-optical networks.

REFERENCES

[1] Hao Qin, Zengji Liu, Shi Zhang, Aijun Wen, " Routing and wavelength assignment based on genetic algorithm", Communications Letters, IEEE , Volume: 6 , Issue: 10 , Oct. 2002, Pages:455 – 457.

[2] Inkret, R., Mikac, B., Podnar, I., " A heuristic approach to wavelength assignment in all-optical networks" Electrotechnical Conference, 1998. MELECON 98., 9th Mediterranean , Volume: 2 ,18-20 May 1998, Pages:759 - 763 vol.2.

[3] Ramaswami, R., Sivarajan, K.N., " Routing and wavelength assignment in all-optical networks", Networking, IEEE/ACM Transactions on , Volume: 3 , Issue: 5 , Oct. 1995 Pages:489 – 500.

[4] D. Beckmann, U. Killat, "Routing and Wavelength Assignment in Optical Networks using Genetic Algorithms", European Transactions on Telecommunications, pp. 537--544, September 1999.

[5] Xiaowen Chu, Bo Li, Zhensheng Zhang, " A dynamic RWA algorithm in a wavelength-routed all-optical network with wavelength converters", INFOCOM 2003. Volume: 3 , 30 March - 3 April 2003, Pages:1795 – 1804.

[6] J. O'Rourke, *Computational Geometry in C*, Cambridge University Press, New York, 1994.

[7] L. Davis, ed., *Handbook of Genetic Algorithms*, Van Nostrand Reinhold, New York, 1991.