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A New Cost Function to Solve RWA Problem in Wavelength Routed Optical Network Using Genetic Algorithms

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Abstract—**Routing and Wavelength Assignment Problem in wavelength division multiplexed optical network is represented as an Integer Linear Program which is found to be NP-Complete. Our attention is devoted to such networks operating under wavelength continuity constraint, in which a lightpath must occupy the same wavelength on all the links it traverses. In setting up a lightpath, a route must be selected and a wavelength must be assigned to the lightpath. We have proposed ILP formulations for $MaxRWA$ and $MinRWA$ problems with a new cost function. The cost function is based on congestion with delay and hop-count is of secondary importance. Genetic Algorithms provide an attractive approach to compute sub-optimal solutions for the RWA problem. This paper discusses a genetic algorithm way of solving the RWA problem on standard networks such as ARPANET.**

Keywords- Routing and Wavelength Assignment; Integer Linear Program; WDM Networks; Wavelength continuity constraint; lightpath; Genetic Algorithm

I. INTRODUCTION

Wavelength Division Multiplexing (WDM) in optical networks has been gaining rapid acceptance as a means to handle the ever-increasing bandwidth demands of Internet users [1]. WDM technique exploits the huge bandwidth of optical fiber by overcoming the optoelectronic bottleneck at intermediate nodes. WDM optical networks [2] use lightpaths to exchange information between source-destination node pairs. A lightpath is an all optical logical connection established between a node pair. Given a set of connections, the problem of setting of lightpaths by routing and assigning a wavelength to each connection is called Routing and Wavelength Assignment (RWA) problem.

The additional complexity of the RWA problem arises from the following two facts:

Wavelength Continuity Constraint: A lightpath must use the same wavelength on all the links from source to destination edge node.

Wavelength Distinct Constraint: All lightpaths sharing the same link must use distinct wavelengths.

As per the traffic pattern [4], the RWA problem can have the following two variations:

Static Lightpath Establishment (SLE) problem: Here, the set of connection requests to be established are known in advance. The basic objective is to maximize the honored requests with minimum use of network resources like the number of wavelengths and the number of fibers in the network.

Dynamic Lightpath Establishment (DLE) Problem: Here, the connection requests arrive according to a stochastic process. The basic objective is to minimize the average blocking probability of the online requests.

The SLE problem can be formulated as an Integer Linear Program (ILP) which is found to be NP-Complete [6]. For large networks, rounding heuristics [5] are used to convert the variables of the ILP into either 0 or 1 and accordingly the routing sub-problem is solved. For assigning wavelengths to the established lightpaths, the graph coloring technique is used.

The DLE problem is more difficult to solve. So, we use heuristic methods to solve both the routing sub-problem and wavelength assignment sub-problem. To solve the routing sub-problem the heuristic options used are: Fixed Routing, Fixed Alternate Routing and Dynamic Routing. Among these, the protocol overhead for Fixed Routing scheme is most simple while Dynamic Routing scheme provides the best performance in term of blocking probability. To solve the wavelength assignment sub-problem, various heuristics used are Random wavelength assignment, First Fit wavelength assignment, Least Used (LU) wavelength assignment and Most Used (MU) wavelength assignment scheme.

In a wavelength routed optical network, if an intermediate routing node is able to convert an incoming optical signal in one wavelength to an outgoing signal in another wavelength, then such a network is called as a wavelength convertible network. In such networks, wavelength continuity constraint is relaxed and the RWA problem reduces to a classical routing problem. If a wavelength converter is capable of converting from one wavelength to any other wavelength in the wavelength domain, and if every routing node of the optical network is possessed with such converters then we call such a network with full wavelength conversion capability [4].

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Wavelength converters are expensive devices and hence by intelligently putting a cost to these converters we can ensure that converters are used only when there is no wavelength contiguous path that can be established from the source to the destination node. The cost of the converter should be at least equal to the cost of the longest wavelength contiguous path possible for a source-destination pair.

II. RELATED WORK

Various strategies have been proposed in current literature that addresses heuristic approaches to solve RWA problem in all optical networks. However, there are relatively few studies that investigate the performance of soft computing approaches to solve the RWA problem. A search of the IEEE Explorer database shows a published letter [7], where the Max-RWA model has been modified by introducing limited-range wavelength converters at the intermediate nodes. The optimization objective is to maximize the establishment of connection requests with least use of wavelength converters. The Max-RWA problem is formulated as an integer linear program and then solved using genetic algorithm.

In [8], M. C. Sinclair has given a minimum cost wavelength-path routing and wavelength allocation using a Genetic algorithm / Heuristic hybrid algorithm. A cost model has been adopted which incorporates dependency on link wavelength requirements. The hybrid algorithm uses object-oriented representation of networks and incorporates four functions: path-mutation, single-point crossover, re-route and shift-out. In addition, an operator probability adaptation mechanism is employed to improve operator productivity.

In [3], Zhong Pan developed a new Fitness Function to solve the routing sub-problem of the RWA problem using genetic algorithm. The objective was to route each lightpath in such a way to minimize the wavelengths needed to honor all the lightpaths in a static lightpath establishment scenario. The secondary targets were to minimize the total cost in setting all the lightpaths and to minimize the maximum cost of a lightpath. The cost was calculated in term of route-length from source to destination node.

In [9], D. Bisbal et al. proposed a novel genetic algorithm to perform dynamic routing and wavelength assignment in wavelength routed optical networks with no wavelength converters. By means of simulation experiments, they obtained a low average blocking probability and a very short computation time. Besides, by controlling the evolution parameters of the genetic algorithm, a high degree of fairness among the connection requests was achieved. They also developed an extension to the proposed algorithm with the aim at providing protection to the lightpaths in the optical layer.

III. PROBLEM DEFINATION

The optical network can be modeled as an undirected graph $G = (V, E)$; where V is the set of routing nodes and E is the set of bidirectional fiber links. Let W be the set of wavelengths supported by every fiber link of the optical network. Then a lightpath can be viewed as a pair (p, w) where p is the physical path between the source node and the destination node and $w \in W$ is selecting a contiguous wavelength for the physical path p .

Let K = Set of lightpaths to be established

Then the lower bound on the set of wavelengths W can be formulated as:

$$|W| \geq \frac{\sum_{k \in K} |k|}{|E|} \tag{1}$$

Here,

$|k| =$ Length of $k \in K$ in term of all links $(m, n) \in E$ traversed to reach the destination

$|E| =$ Number of fiber links in the optical network

The RWA problem can be realized as an integer linear program and based on this formulation RWA problem has two variations as:

- $MaxRWA$ problem
- $MinRWA$ problem

A. *Proposed ILP formulation for $MaxRWA$ problem*

The variables required for the ILP are:

$b_k =$ This variable is set to 1 if the lightpath $k \in K$ is established; otherwise it is set to 0.

$b_k^w =$ This variable is set to 1 if lightpath $k \in K$ uses wavelength $w \in W$, otherwise it is set to 0.

$b_k^w(m, n) =$ This variable is set to 1 if lightpath $k \in K$ uses wavelength $w \in W$ in the fiber link between the intermediate nodes m, n where $(m, n) \in E$ and $m, n \in V$, otherwise it is set to 0.

The objective function is to maximize the established connection requests and can be interpreted as:

$$Max \sum_{k \in K} b_k \tag{2}$$

Subject to:

- Wavelength Continuity Constraint:

$$\sum_{w \in W} b_k^w \leq 1; \text{ for every } k \in K \tag{3}$$

- Wavelength Distinct Constraint:

$$\sum_{k \in K} b_k^w(m, n) \leq 1; \text{ for every } w \in W \text{ and } (m, n) \in E \tag{4}$$

The wavelength continuity constraint justifies that every lightpath uses only wavelength to reach the destination and the wavelength distinct constraint shows that a wavelength of a particular link can be allocated at best to a single lightpath.

B. *Proposed ILP formulation for the $MinRWA$ problem*

The variables required for the ILP are:

$L_k^w(m,n)$ =This variable is set to 1 if lightpath $k \in K$ uses wavelength $w \in W$ in the fiber link between the intermediate nodes m,n where $(m,n) \in E$ and $m,n \in V$

L_k^w = This variable is set to 1 if lightpath $k \in K$ is loaded with wavelength $w \in W$

The objective function is to minimize the average load in the links of the optical network and can be interpreted as:

$$Min \sum_{k \in K} \sum_{w \in W} L_k^w(m,n) \quad (5)$$

Subject to:

- Wavelength Continuity Constraint:

$$\sum_{w \in W} L_k^w \leq 1 \text{; for every } k \in K \quad (6)$$

- Wavelength Distinct Constraint:

$$\sum_{k \in K} L_k^w(m,n) \leq 1 \text{; for } w \in W \text{ and } (m,n) \in E \quad (7)$$

IV. WORK PROPOSED

Based on the literature survey, we propose a new cost function to solve the routing and wavelength assignment problem using genetic algorithm. Various factors that we consider to formulate the cost function are congestion, delay and hop-count. The factor congestion actually determines the number of wavelengths required to establish all the lightpaths known offline. Delay is the factor required to put a limit on the connection set up time of a lightpath. And, the factor hop-count sums the number of intermediate hops traversed by the lightpath to reach the destination.

So, by intelligent routing of the known lightpaths, we can minimize the values associated with these factors that will in turn minimize the value of the cost function. A lower value of the factor congestion satisfies the initial objective of the RWA problem that is to maximize the established connections with minimum number of wavelengths used. Again, by lowering the congestion of the most congested link of the network, we can achieve improved load balancing in the optical network. While solving the Dynamic Lightpath Establishment problem, congestion greatly influence the blocking probability of the future connection requests. By minimizing the delay factor we try to enhance the connection set up time of the lightpaths. Similarly, when a lightpath traverses more number of intermediate hops, the more crosstalk it accumulates. So, by putting a restriction on the factor hop-count we try to minimize the signal distortion.

While trading off among the above three factors to formulate a new cost function, our primary importance must be given to congestion. The other two factors delay and hop-count are of secondary importance. So the cost function may be formulated as:

$$C = 0.9\frac{con}{|K|} + 0.08\frac{totdelay}{|K|(|V|-1)d} + 0.01\frac{\max delay}{(|V|-1)d} + 0.01\frac{hcount}{(|V|-1)}$$

Here,

$con =$ Congestion of the most congested link of the network and defines the number of wavelengths used to honor all the lightpaths

$totdelay =$ Sum of the connection set up times of all lightpaths

$\max delay =$ Maximum connection set up time of a lightpath and defines an upper boundary on the connection set up time

$hcount =$ Maximum number of intermediate hops traversed by a lightpath and defines an upper boundary on the intermediate hops used by the lightpath to reach the destination.

$d =$ Maximum delay of a fiber link in the network

Each factor of the cost function is divided by its respective maximum to maintain normalization among solutions available to route the lightpaths.

V. APPLICATION OF GENETIC ALGORITHM

Genetic Algorithms are a class of probabilistic searching algorithms based on the mechanism of biological evolution. A GA (Genetic Algorithm) begins with an initial population of individuals (also called chromosomes); each of which represents a feasible solution to the problem being tackled. Then the GA applies a set of genetic operations such as crossover or mutation to the current population to generate a better one. This process is repeated until a good solution is found or after predefined number of iterations. [10]

The working of the algorithm to solve the RWA problem is described as follows.

A. *The Chromosome Structure*

The chromosome is a group of vectors coded as $\begin{bmatrix} p_1 \\ : \\ p_{|K|} \end{bmatrix}$

where each vector p_i is a lightpath represented as $(n_{i0} \quad \ldots \quad n_{ih(i)})$; $n_{i0},\ldots n_{ih(i)} \in V$ and $h(i)$ represents the number of intermediate hops traversed by the lightpath and n_{i0} is the source node and $n_{ih(i)}$ is the destination node for the lightpath.

B. *Initial Population*

To create the initial population, we take the help of dynamic routing heuristic [4] that collects all possible routes from the source node to the destination node. Each source node $s \in V$ in the network maintains a routing table R_s that collects all possible routes to every other node in the network. So, $R_{st} \subset R_s$ denotes the set of routes from node

s to node t. By searching these routing tables, available routes for an offline request can be calculated. A possible combination, by selecting an available route from every offline connection request yields a chromosome. All such combinations will generate different chromosomes and thus the initial population gets created.

C. Cost Function

Cost function can be considered as the target function to be minimized. The cost function is same as depicted in the proposed work. While penalizing a chromosome with a certain cost, it must be checked whether a contiguous wavelength is available for every vector of the chromosome. If it is not so, then the chromosome will be penalized with a very high cost. The advantage of such technique is that such chromosomes die early when the genetic algorithm propagates.

D. Selection of chromosomes for the next generation

The chromosomes of the next generation are selected from the current population by a spinning roulette wheel method [11].

The cost values of the chromosomes in the current population can be normalized as follows.

$$C_g = C_g - worst(C) \quad (8)$$

C_g = Cost of the chromosome g in the current population

$worst(C)$ = The chromosome penalized with highest cost in the current population

The probability that a chromosome g is selected from the current population is given as $\Pr_g = \frac{C_g}{\sum_g C_g}$ (9)

The cumulative probability of the chromosome g is calculated as $PR_g = \sum_{u=1}^{g} \Pr_u$ (10)

Then spin the roulette wheel and for each spin, a random number is generated v such that v is in $[0,1]$.

If $PR_{g-1} < v \le PR_g$; then select the chromosome g for the next population.

E. Crossover

Crossover modifies two chromosomes by exchanging building blocks between the two and may lead to descendants which combine the merits of both their parents. According to a crossover rate, a selected chromosome is crossovered with another selected chromosome.

Here, we apply two-point crossover genetic operator technique for mating two selected chromosomes. Two crossover points $(cp1, cp2)$ are selected randomly such that $(0 < cp1 < cp2 <= |K|)$. Let the partial vectors between $cp1$ and $cp2$ of each selected chromosome be swapped, rendering two new chromosomes.

F. Mutation

Mutation modifies a selected chromosome with randomness and the resulting chromosome is supposed to possess a lower cost value. Mutation also helps in avoiding early convergence that may produce sub-optimal result. According to a certain mutation rate a chromosome is mutated. The percentage of vectors of the selected chromosome to be modified under mutation operator is calculated. For each such vector $p_i = (n_{i0} \quad \ldots \quad n_{ih(i)})$; randomly choose two nodes n_{ij} and n_{ik} such that $j < k$. Then searching the routing table $R_{n_{ij} \quad n_{ik}} \subset R_{n_{ij}}$; another route must be found that is link disjoint with the existing route from n_{ij} to n_{ik} in the original vector and the replacement modifies the vector concerned.

As we are replacing a sub-route of the vector with its edge disjoint counterpart, it will help us in achieving fault-tolerance in the optical network.

VI. SIMULATION AND RESULT

For the simulation work, we assume that the network is static and circuit-switched. The fiber links are bidirectional. There is no limit on the number of wavelengths a fiber can carry.

The RWA problem has been implemented using genetic algorithm approach based on the proposed cost function and labeled as GA-2. For performance comparisons, we extracted an existing genetic algorithm approach labeled as GA-1 from the literature [3], where the cost function is based on congestion and delay without considering hop-count as an additional parameter. With slight variations, the cost function looks like:

$$C = 0.9\frac{con}{|K|} + 0.08\frac{totdelay}{|K|(|V|-1)d} + 0.02\frac{\max delay}{(|V|-1)d} \quad (11)$$

The RWA problem, as addressed and solved in the proposed research work has been successful in getting reasonable number of wavelengths to honor all the lightpaths in less time and with less cost.

The performance parameters considered are:

Execution time: This is the time required for taking the routing decision and assigning wavelengths to the lightpaths under wavelength continuity constraint and wavelength distinct constraint.

Total Cost of Paths: This is the sum of the connection set up time of all lightpaths.

Number of Wavelengths Required: This signifies the amount of network resources consumed to establish all the lightpaths.

The standard network considered for simulation is ARPANET shown in fig. 1; which has 20 nodes connected with 25 links. The genetic algorithm is implemented and simulated for this network with different set of connection requests and the results are obtained for the above parameters as shown in fig. 2, fig. 3 and fig. 4.

VII. CONCLUSION AND FUTURE WORK

In the proposed work, we address the routing and wavelength assignment problem in all optical networks. Our primary concern is to use nature inspired solutions like genetic algorithm as methods for routing and wavelength assignment in all optical network.

In the future, the cost function proposed can be modified so that it can be applicable to the network with sparse wavelength conversion capability. Fairness among connection requests and achieving fault tolerance are two other issues deserve more investigation in the future.

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REFERENCES

[1] B. Mukherjee, "Optical communication Networks," Mc Graw-Hill, New York, 1997.

[2] C. Sivaramamuthy and M. Guruswamy, "WDM Optical Networks-Concepts, Design and Algorithms," Prentice Hall, 2002, ISBN: 0-13-060637-5.

[3] Zhong Pan, "Genetic Algorithm for Routing and Wavelength Assignment Problem in All-optical Networks," A Technical Report Submitted to the Depatrment of Electrical and Computer Engineering, University of California, Davis, 2002.

[4] Hui Zang, J. P. Jue and B. Mukherjee, " A Review of Routing and Wavelength Assignment Approaches for Wavelength Routed Optical WDM Networks," Optical Networks magazine, vol. 1, no.1, pp. 47-60, Jan.2000.

[5] D. Banerjee and B. Mukherjee, " A practical Approach for Routing and Wavelength Assignment in Large Wavelength-Routed Optical Networks," IEEE Journal on Selected Areas in Communications,vol. 14, no. 5, pp. 903-908, June 1996.

[6] R. Ramaswami and K. N. Sivarajan, " Routing and Wavelength Assignment in All-Optical Networks," IEEE/ACM Transaction on Networking, vol. 3, no. 5, pp.489-500, Oct. 1995.

[7] Hao Qin, Zengji Liu, Shi Zhang and Aijun Wen, " Routing and Wavelength Assignment based on Genetic Algorithm," IEEE Communication Letters, vol. 6, no.10, pp.455-457, Oct. 2002.

[8] M. C. Sinclair, " Minimum Cost Wavelength-Path Routing and Wavelength Allocation Using a Genetic Algorithm/ Heuristic Hybrid Approach," IEEE Proceedings on Communications, vol. 146, no. 1, pp. 1-7, Feb. 1999.

[9] D. Bisbal et al., " Dynamic Routing and Wavelength Assignment in Optical Networks by means of Genetics Algorithms," Photonic Networks Communications, vol. 7, no. 1, pp. 43-58, 2004.

[10] D. E. Goldberg, "Genetic Algorithms in Search, Optimization and Machine Learning," Addison-Wesley Publishing Company Inc., 1997.

[11] Z. Michalewicz, "Genetic Algorithms + Data Structure = Evolution Programs," Third rev. and extended ed., 1996.

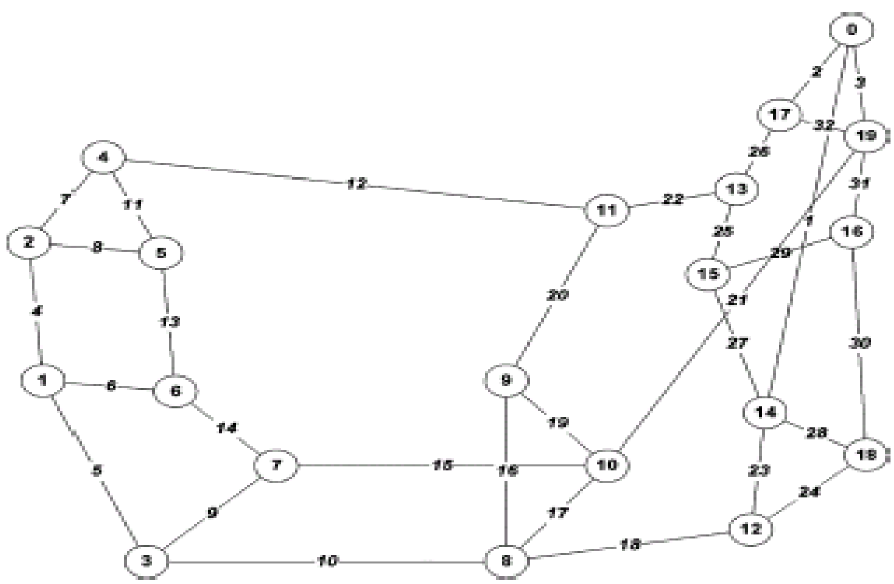

Figure 1. ARPA Network

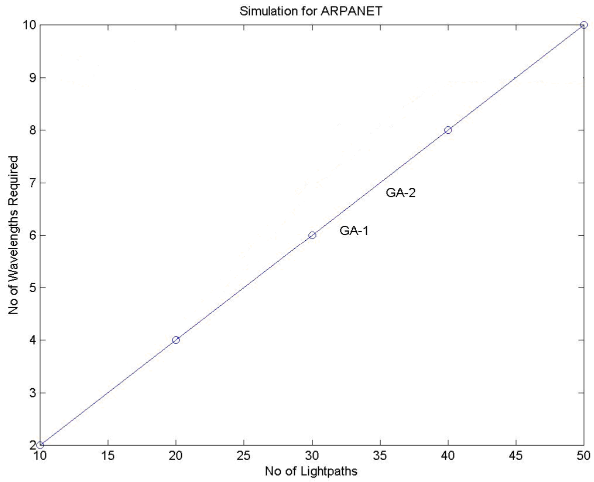

Figure 2. No of Wavelengths Required vs. No of Lightpaths

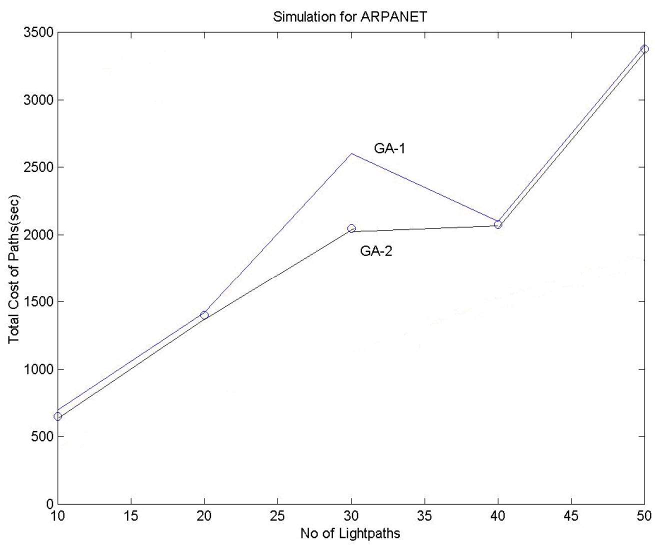

Figure 3. Total Cost of Paths vs. No of Lightpaths

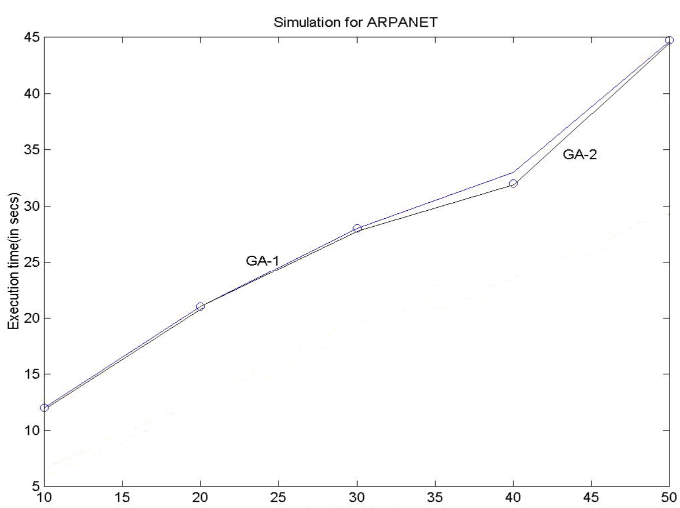

Figure 4. Execution Time vs. No of Lightpaths