Genetic Algorithm techniques to solve Routing and Wavelength Assignment problem in Wavelength Division Multiplexing all-optical networks

Ravi Sankar Barpanda, Ashok Kumar Turuk, Bibhudatta Sahoo, Banshidhar Majhi
Department of Computer Science and Engineering
National Institute of Technology
Rourkela 769008, India
Email: {barpandar,akturuk,bdsahu,bmajhi}@nitrkl.ac.in

***Abstract*—Routing and Wavelength Assignment (RWA) problem in Wavelength Division Multiplexed (WDM) optical networks assumes assigning the routes and wavelengths to be used to create the lightpaths on behalf of the connection requests. The RWA problem belongs to the class of combinatorial optimization problems. The optimal solution to the RWA problem is found to be NP-hard and thus suited to heuristic approaches. We formulate an Integer Linear Programming (ILP) problem to model the RWA problem as an optimization problem and solve the formulated ILP using Genetic Algorithm (GA) heuristic to obtain a near optimal solution in polynomial time. Our primary optimization objective is the establishment of connection requests with minimum congestion among the individuals. The secondary targets are to minimize the hop count, route length, the number of fiber links utilized to honor all the lightpath requests. The GA based heuristic approach is simulated on ARPANET (Advanced Research Project Agency NETwork) and the results obtained for the multi objective GA are compared with the single objective GA. The results show that multi objective GA performs better than single objective GA while optimizing different network parameters.**

I. Introduction

The bandwidth demand of Internet users has been increasing rapidly due to the growth of the population of Internet users and the popularization of online applications and services that require high bandwidth, such as voice chat, video streaming, P2P file sharing, grid computing, HDTV programming and optical storage area networks[1], [2]. Wavelength Division Multiplexing (WDM) is a promising technology to serve as the backbone for future Wide Area Networks (WAN) because of its capability to exploit the huge bandwidth of optical fibers [3], [4], [5], [6], [7], [8], [9], [10]. WDM technique increases the transmission capacity by using multiple non interfering channels at different carrier wavelengths. In general networks to route, add and terminate wavelengths we need Wavelength Cross-connects (WXCs) [11], [12] (also known as Optical Cross-connects or OXCs) whose block diagram is depicted in Fig. 1. WDM optical networks use lightpaths [3], [4], [13], [14], [15] to exchange information between node pairs. A lightpath is an all-optical logical connection that does not require processing or buffering at intermediate nodes. In Fig. 2, we have considered a small optical network with five routing nodes and eight fiber links and analyzed the establishment of five lightpath requests using two carrier wavelengths.

978-1-4244-8953-4/11/$26.00 © 2011 IEEE

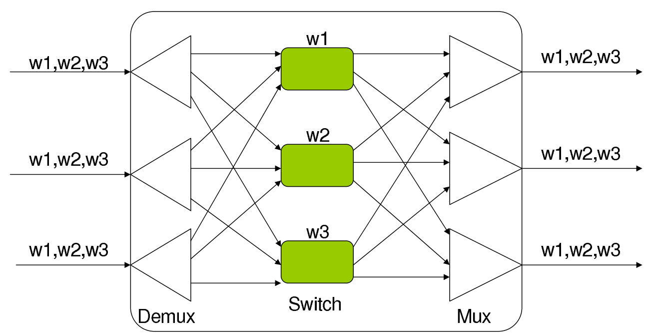

Fig. 1: Wavelength cross-connecting Switch

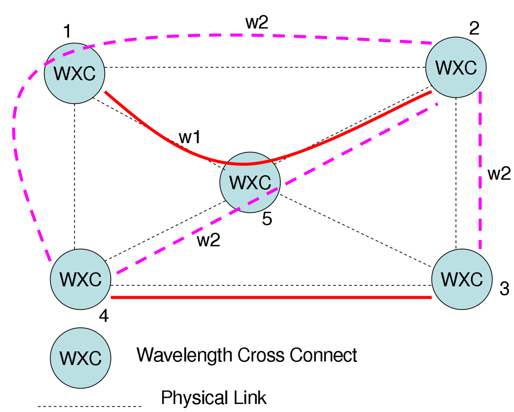

Fig. 2: Switching strategy in WDM networks

Given a set of lightpaths that need to be established, the routing problem in WDM networks consists of two subproblems that may be solved concurrently or sequentially. The first subproblem is to determine the physical links that will define each lightpath. The second subproblem is to assign a wavelength to each lightpath under wavelength continuity constraint if the network does not have wavelength conversion capability. This is referred to as the routing and wavelength assignment (RWA) problem [15], [16]. The RWA problem is typically divided into two types: static and dynamic RWA problems.In the static case, the entire set of connections is given in advance, the problem is to define lightpaths for these connection requests in an optimal way so as to minimize the network resource or to minimize the total blocking probability. Alternatively, a static RWA algorithm may attempt to set up as many of connection requests as possible given a fixed number of wavelengths per fiber link. In the dynamic case, a lightpath is setup only by the time a connection request arrives and it will be released after some duration. The general objective of dynamic RWA algorithms is to minimize the total number of connections that are blocked [7], [15]. The static RWA problem can be formulated as an integer linear programming problem which is found to be NP-hard [15], [17], [18], [19]. For large networks, randomized rounding heuristics are used to restrict the variables of the ILP to keep integral values only, thereby solving the routing sub-problem of the RWA problem. Once a route is defined to each lightpath, we assign wavelength colors to these established lightpaths under wavelength continuity constraint such that two lightpaths sharing a common fiber link must posses different wavelength colors. This is called wavelength distinct constraint. Assigning wavelength colors to lightpaths reduces to the graph coloring problem in polynomial time[15], [17]. The dynamic RWA problem is more difficult to solve therefore, heuristics methods are generally employed. Heuristics exist for both the routing subproblem and the wavelength assignment subproblem [3], [14], [15], [17].

The RWA problem with its variations is summarized as follows:

TABLE I: RWA Classification

Classification	RWA
Traffic Type	Static,Dynamic
Objective function	Max-RWA,Min-RWA
ILP formulation	Link-based, Path-based
Wavelength conversion	Full,Sparse,None
Fiber multiplicity	Single,Multiple
Request multiplicity	Single,Multiple

II. Related Work

Various strategies have been proposed in current literature that address a range of heuristic and meta heuristic approaches to solve the RWA problem in all optical networks. A detailed review displays a published letter [20], 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 [21], [22], M. C. Sinclair has given a minimum cost wavelength-path routing and wavelength allocation scheme using a Genetic algorithm / Heuristic based hybrid algorithm. A cost model has been adopted which incorporates dependency on link and 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 [23], Zhong Pan solved the routing sub-problem of the RWA problem using genetic algorithm. The objective was to define route for each lightpath such that the number of wavelengths used are minimized while establishing all the static lightpaths. The secondary targets were to minimize the total cost in setting all the lightpaths and the maximum number of intermediate hops traversed by a lightpath. In [24], D. Bisbal et al. proposed a novel genetic algorithm to perform dynamic routing and wavelength assignment in wavelength routed optical networks under wavelength continuity constraint. Through simulation, they obtained a low average blocking probability associated with a connection request and a very short computation time. 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. In previous linear formulations [25] for the RWA problem the paths that the source-destination pair is allowed to take had to be specified beforehand. This is called as the path formulation ILP. As the number of paths between a node pair is exponential to the number of nodes of the graph; the path formulation will have to restrict itself to a few paths per node pair. When only a limited number of paths are considered, the path formulation ILP approach may yield a sub-optimal solution. In [26], Krishnaswami and Sivarajan proposed link based ILP formulations, i.e., the constraints are defined on the links (edges or arcs) of the network. The advantage of this formulation is that we do not specify the paths beforehand, but allow the ILP solver to choose any possible path and any possible wavelength for a source-destination pair and also the number of constraints in this formulation are polynomial on the number of nodes.

III. Work Proposed

Based on the literature review, we formulate a link based ILP to model the RWA problem as an optimization problem. Introducing additional constraints to the objective function of the formulated ILP, we establish lightpaths which are immune to signal distortion and crosstalk. A constraint on the number of intermediate hops traversed by a lightpath ensures less crosstalk accumulated by it, while in the absence of wavelength continuity constraint, a restriction on the number of wavelength converters used by a lightpath ensures less signal distortion.With reference to [26], we add further constraints to the formulated ILP such that the lightpaths to be established will avoid creating loops while traversing between node pairs. These constraints help in avoiding unnecessary consumption of network resources in terms of wavelengths and fiber links, thereby helping us to reduce the average blocking probability associated with future arrivals. The formulated ILP is tailored with Genetic Algorithm heuristic technique and implemented on ARPANET to establish different sets of lightpath requests. The results obtained for the single objective GA are compared with their multi objective counterpart and the comparison analysis is based on the ability to optimize various network parameters while establishing these distinct sets of lightpath requests.

IV. ILP FORMULATION

The optical network is 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. Each fiber link supports the same number of wavelengths W. The symbols with their usual notations are defined as follows:

- V =the set of nodes in the network.
- E =the set of bidirectional fiber links in the network
- W =the set of non-interfering wavelength channels supported by every fiber link in the network
- (i, j) =the source-destination node pairs; $\{i, j\} \in V$
- D =the demand matrix of connection requests, where D_{ij} refers to a positive integral value stating the maximum demand between the node pair (i, j) and $D_{ij} = D_{ji}$
- $\omega^-(v)$ = the set of fiber links used by a lightpath to enter the node v
- $\omega^+(v)$ = the set of fiber links used by a lightpath to leave the node v

The formulated ILP handles the lightpath requests individually. An individual request is identified by its source node s_k and destination node d_k.

The variables required for the ILP formulation are defined as follows:

$$b_k^w = \begin{cases} 1; if\ the\ lightpath\ k\ is\ established\ with \\ wavelength\ w \\ 0; otherwise \end{cases}$$

$$b_k^{w,e} = \begin{cases} 1; if\ the\ lightpath\ k\ is\ established\ with \\ wavelength\ w\ on\ link\ e \\ 0; otherwise \end{cases}$$

The primary optimization objective is to minimize the congestion of the most congested link in the network thereby reducing the network load. The secondary objectives are to minimize the connection set up time, the number of intermediate hops traversed and the number of fibers used to honor all the lightpath requests in the demand matrix. The network design formulations to optimize different objective functions are enumerated as follows:

- **Minimizing the congestion of the most congested link in the network:**

$$Minimize \quad \max_{e \in E} \sum_{k \in K} \sum_{w \in W} b_k^{w,e} \tag{1}$$

- **Minimizing the maximum number of intermediate hops traversed:**

$$Minimize \quad \max_{k \in K} \sum_{e \in E} \sum_{w \in W} b_k^{w,e} \tag{2}$$

- **Minimizing the number of fiber links used to honor all the lightpaths:**

$$Minimize \quad \left| \{e \in E | \sum_{k \in K} \sum_{w \in W} b_k^{w,e} > 0\} \right| \tag{3}$$

- **Minimizing the maximum route length:**

$$Minimize \quad \max_{k \in K} \sum_{e \in E} (d_e | \sum_{w \in W} b_k^{w,e} > 0) \tag{4}$$

where d_e = delay associated with link e

- **Minimizing the total route length:**

$$Minimize \quad \sum_{k \in K} \sum_{e \in E} (d_e | \sum_{w \in W} b_k^{w,e} > 0) \tag{5}$$

where d_e = delay associated with link e

The above objective functions subject to the following constraints:

- **Wavelength continuity constraint:**

$$\sum_{w \in W} b_k^w \leq 1; \forall k \in K \tag{6}$$

The wavelength continuity constraint enforces a lightpath to use the same wavelength among all the traversed links.

- **Wavelength distinct constraint:**

$$\sum_{k \in K} b_k^{w,e} \leq 1; \forall w \in W and \forall e \in E \tag{7}$$

A distinct wavelength of a particular fiber link can be at best allocated to a single lightpath.

- **Demand constraint:**

$$|\{k \in K| \sum_{e \in \omega^-(i)} \sum_{w \in W} b_k^{w,e} - \sum_{e \in \omega^+(i)} \sum_{w \in W} b_k^{w,e} = -1 \wedge \sum_{e \in \omega^+(j)} \sum_{w \in W} b_k^{w,e} - \sum_{e \in \omega^-(j)} \sum_{w \in W} b_k^{w,e} = -1\}| \leq D_{ij} \tag{8}$$

The number of established lightpaths between a node pair (i, j) can not exceed its maximum demand.

- **Integer constraint:**

$$b_k^w, b_k^{w,e} \in \{0, 1\} \tag{9}$$

The required variables of the ILP should keep integral values only.

- **Consistency constraint:**

$$b_k^w > b_k^{w,e} \tag{10}$$

A blocked lightpath can not claim network resources in terms of fiber links and free wavelengths.

- **Wavelength reservation constraint:**

$$\sum_{e \in \omega^-(v: v \in V - \{s_k, d_k\})} b_k^{w,e} - \sum_{e \in \omega^+(v: v \in V - \{s_k, d_k\})} b_k^{w,e} = 0; \forall k \in K and \forall w \in W \tag{11}$$

The number of lightpaths between a node pair (s_k, d_k) entering an intermediate node v with wavelength w must be equal to the number of lightpaths between (s_k, d_k) leaving node v with wavelength w.

- **No looping constraint around source node:**

$$\sum_{e\in\omega^-(s_k):s_k\in V}\sum_{w\in W} b_k^{w,e} = 0; \forall k \in K \quad (12)$$

The set $\omega^-(s_k)$ denotes the set of fiber links used by a lightpath between node pair (s_k, d_k) to enter the source s_k. Nullifying the set $\omega^-(s_k)$ for all such lightpaths between (s_k, d_k) ensures prevention of loops around the source node.

- **No looping constraint around destination node:**

$$\sum_{e\in\omega^+(d_k):d_k\in V}\sum_{w\in W} b_k^{w,e} = 0; \forall k \in K \quad (13)$$

The set $\omega^+(d_k)$ denotes the set of fiber links used by a lightpath between node pair (s_k, d_k) to leave the destination d_k. Nullifying the set $\omega^+(d_k)$ for all such lightpaths between (s_k, d_k) ensures prevention of loops around the destination node.

- **No looping constraint around intermediate nodes:**

$$\sum_{e\in\omega^-(v):v\in V-\{s_k,d_k\}}\sum_{w\in W} b_k^{w,e} \leq 1; \forall k \in K \quad (14)$$

$$\sum_{e\in\omega^+(v):v\in V-\{s_k,d_k\}}\sum_{w\in W} b_k^{w,e} \leq 1; \forall k \in K \quad (15)$$

$$\sum_{e\in\omega^+(v):v\in V-\{s_k,d_k\}}\sum_{w\in W} b_k^{w,e} - \sum_{e\in\omega^-(v):v\in V-\{s_k,d_k\}}\sum_{w\in W} b_k^{w,e} = 0; \forall k \in K \quad (16)$$

A lightpath may enter and leave an intermediate node at most one time to avoid creation of loops around it.

- **Hop-Count Constraint:**

$$\sum_{e\in E}\sum_{w\in W} b_k^{w,e} \leq H where\ H = d(G) + \alpha \quad (17)$$

This constraint defines the upper bound on the number of intermediate hops that can be used by a lightpath to ensure less crosstalk accumulated by it. The upper bound H can be calculated from the diameter of the graph G . The diameter $d(G)$ of the graph G can be calculated as follows:

$$d(G) = \max_{(s_k,d_k)\in V\times V}\{d(s_k, d_k)\} \quad (18)$$

where, $d(s_k, d_k)$ is the distance between the node pair (s_k, d_k) and calculated as the minimum number of edges in a path from node s_k to node d_k.
The value be chosen for H can not be less than $d(G)$ and hence stated as:

$$H = d(G) + \alpha \quad (19)$$

The value for α depends on the routing heuristic used to solve the routing part of the RWA problem.

Lemma:

Under wavelength continuity constraint, the congestion of the most congested link in the network defines the lower bound on the number of wavelengths required to establish all the lightpaths in the demand matrix.

In the following exemplary network, the establishment of three lightpath requests requires three distinct wavelength colors while keeping the congestion level at two, among all the links in the network. It reveals that the congestion level of the most congested link in the network defines the lower bound on the actual number of wavelengths required to establish all the lightpath requests in the traffic matrix.

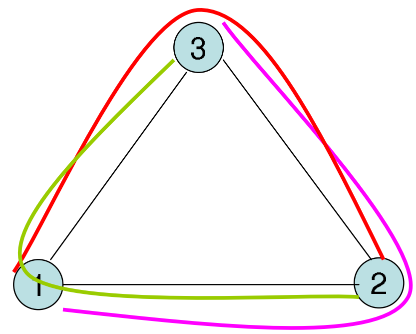

Fig. 3: An exemplary network

The lemma may be stated by the following formulation:

$$\max_{e\in E}\sum_{k\in K}\sum_{w\in W} b_k^{w,e} \leq \sum_{k\in K}\sum_{w\in W} b_k^w \quad (20)$$

The above formulated ILP can be modified to make it suitable for wavelength convertible networks. In such networks, the wavelength continuity constraint is relaxed and restated as follows:

$$\sum_{w\in W} b_k^w \leq \delta; \forall k \in K \quad (21)$$

where δ defines the upper bound on the number of wavelength converters that can be used by a lightpath request.

The following enumeration explains the technique of switching the wavelength channels along the lightpaths in different types of wavelength convertible networks.

- Networks with sparse wavelength conversion capability:
  - At nodes without wavelength converters:

$$b_k^{w,(e1|e1\in\omega^-(v|v\in V-\{s_k,d_k\}))} = b_k^{w,(e2|e2\in\omega^+(v|v\in V-\{s_k,d_k\}))} \quad (22)$$

  - At nodes with wavelength converters:

$$\sum_{w\in W} b_k^{w,(e1|e1\in\omega^-(v|v\in V-\{s_k,d_k\}))} = \sum_{w\in W} b_k^{w,(e2|e2\in\omega^+(v|v\in V-\{s_k,d_k\}))} \quad (23)$$

- Networks with all nodes equipped with limited-range wavelength converters:
  If all the routing nodes of the WDM network are equipped with limited range wavelength converters with degree of

conversion Δ, then Eq.23 may split into the following two equations.

$$\sum_{w'\in W} b_k^{w',(e1|e1\in\omega^-(v|v\in V-\{s_k,d_k\}))} = b_k^{w,(e2|e2\in\omega^+(v|v\in V-\{s_k,d_k\}))} \quad where\ w-\Delta \le w' \le w+\Delta \tag{24}$$

$$b_k^{w,(e1|e1\in\omega^-(v|v\in V-\{s_k,d_k\}))} = \sum_{w'\in W} b_k^{w',(e2|e2\in\omega^+(v|v\in V-\{s_k,d_k\}))} \quad where\ w-\Delta \le w' \le w+\Delta \tag{25}$$

V. Genetic Algorithm approach to solve RWA problem

Genetic Algorithms [27], [28], [29], [30] are probabilistic searching algorithms based on the mechanism of biological evolution. 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 $\begin{pmatrix} n_{i0} & ... & n_{ih(i)} \end{pmatrix}$; $n_{i0}, ...n_{ih(i)} \in V$ and $h(i)$ defines the number of hops traversed by the lightpath p_i.

B. Initial Population

For every static 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 of the first generation. For each fiber link$(n_{ij}, n_{i(j+1)})$ in every p_i, disable one link at a time and find minimum cost paths to form a new chromosome. Repeat the process until the population size is reached.

C. Fitness function

The fitness function is the target function to be maximized and is used to reduce the congestion of the most congested link in the network. The fitness function for implementing a single objective genetic algorithm is stated as follows:

$$y1 = 1 - \frac{con}{|K|} \tag{26}$$

The above fitness function is modified by considering the secondary objectives to implement a multi objective genetic algorithm and is stated as:

$$y4 = 1 - 0.90\frac{con}{|K|} - 0.07\frac{tot\_r\_length}{d|K|(|V|-1)} - 0.01\frac{\max\_r\_length}{d(|V|-1)} - 0.01\frac{\max\_h\_count}{|V|-1} - 0.01\frac{tot\_fib}{|E|} \tag{27}$$

where,

- con= Congestion of the most congested link in the network and defines the network load.
- $\max\_h\_count$= Maximum number of hops traversed by a lightpath in a chromosome.
- $\max\_r\_length$= Maximum delay of a lightpath in a chromosome.
- tot_r_length= Total delay in establishing all the static lightpaths.
- tot_fib= Total number of fibers used to honor all the lightpaths in a chromosome.
- d=Maximum delay of a link in the network.

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.

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

$$f(g) = \frac{f(g) - min(f(g))}{max(f(g)) - min(f(g))} \tag{28}$$

where

$f(g)$ = fitness of the chromosome g

$min(f(g))$ =The chromosome with least fitness in the current population

$max(f(g))$ =The chromosome with highest fitness in the current population

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

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

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

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

E. Crossover

In the selected generation, with a certain crossover rate a chromosome is asked for mating with another chromosome.According to a crossover ratio, calculate the number of lightpaths that will be modified. Pick these lightpaths randomly and exchange the picked lightpaths between the two chromosomes.

F. Mutation

In the selected generation, with a certain mutation rate a chromosome is mutated.According to a mutation ratio, calculate the number of lightpaths that will be modified.For each such lightpath $p_i = [n_{i0}, n_{i1}, ..., n_{ih_i}]$,randomly pick two adjacent nodes n_{ij} and $n_{i(j+1)}$. Disable the fiber link between the two nodes and remove all the nodes n_{il} such that $l < j$ and $l > j + 1$. Then calculate the minimum cost path between n_{ij} and $n_{i(j+1)}$ and replace the corresponding portion in p_i using the new path.

VI. Simulation Result

For the simulation work, we deal with the following assumptions:

- The network is static and circuit-switched.
- The network maintains wavelength continuity constraint.
- The fiber links are bidirectional.

- There is no limit on the number of wavelengths a fiber can carry.

The parameters of interest to implement the genetic algorithm are outlined as follows:

- Population size: The number of chromosomes in a given generation. It is kept at 50.
- Maximum number of generations: The number of generations to run. In this simulation work it is restricted to 100.
- crossover probability: The probability with which a selected chromosome undergoes crossover. In the simulation work it is kept at 0.5.
- Mutation probability: The probability with which a selected chromosome undergoes mutation. In the simulation work it is kept at 0.1
- Crossover ratio: The percentage of lightpaths in a selected chromosome will be affected during crossover operation. In this paper, it is limited to 0.2.
- Mutation ratio: The percentage of lightpaths in a selected chromosome will be affected during mutation operation. In this paper, it is limited to 0.2.

The standard network considered for simulation is ARPANET that has 20 nodes and 32 links as depicted in Fig. 4. Both the single objective and multi objective GA are simulated and implemented for this network to satisfy a demand set of 10 lightpath requests as detailed in Table II. Each lightpath is available with its minimum cost path calculated by Dijkstra's algorithm to form the first chromosome of the initial population.

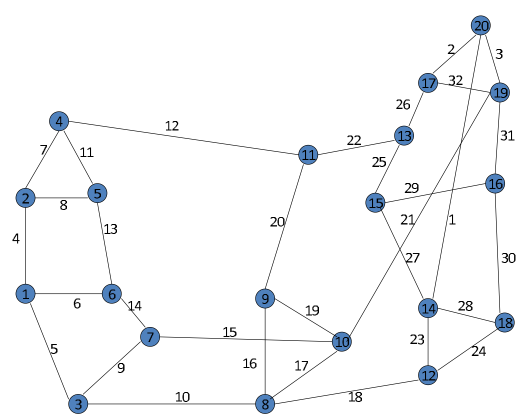

Fig. 4: Advanced Research Project Agency Network

In Table III, we have shown the establishment of the 10 lightpath requests given in the demand set by using single objective GA while in Table IV we have shown the establishment of same set of 10 lightpath requests by using multi objective GA. The performance comparison between single objective and multi objective genetic algorithm is based on the ability to optimize various network parameters and compared in Table V.

TABLE II: Demand set of static lightpath requests

Lightpath	Minimum cost path
n10-n13	n10-n19-n20-n17-n13
n15-n7	n15-n14-n20-n19-n10-n7
n7-n5	n7-n3-n1-n2-n5
n10-n1	n10-n7-n3-n1
n15-n14	n15-n14
n10-n8	n10-n8
n8-n15	n8-n12-n14-n15
n2-n10	n2-n1-n3-n7-n10
n3-n9	n3-n8-n9
n9-n20	n9-n10-n19-n20

TABLE III: Establishment of lightpaths using single objective GA

Lightpath	Allocated route
n10-n13	n10-n19-n20-n17-n13
n15-n7	n15-n14-n12-n8-n10-n7
n7-n5	n7-n3-n1-n2-n5
n10-n1	n10-n7-n3-n1
n15-n14	n15-n13-n17-n20-n14
n10-n8	n10-n8
n8-n15	n8-n12-n14-n15
n2-n10	n2-n4-n11-n9-n10
n3-n9	n3-n8-n9
n9-n20	n9-n10-n19-n20

TABLE IV: Establishment of lightpaths using multi objective GA

Lightpath	Allocated route
n10-n13	n10-n9-n11-n13
n15-n7	n15-n14-n20-n19-n10-n7
n7-n5	n7-n3-n1-n2-n5
n10-n1	n10-n7-n6-n1
n15-n14	n15-n14
n10-n8	n10-n8
n8-n15	n8-n9-n11-n13-n15
n2-n10	n2-n1-n3-n8-n10
n3-n9	n3-n8-n9
n9-n20	n9-n10-n19-n20

TABLE V: Performance comparison between single objective and multi objective GA

Type of GA	comparison
Single objective	The maximum fitness of a chromosome after required number of generations is: 0.800 The network load for establishing 10 lightpaths is: 02 The total delay in establishing all the lightpaths is: 473 The maximum hops traversed by a lightpath: 06 The number of fibers used to honor all the lightpaths: 21 The maximum delay of a lightpath: 100
Multi objective	The maximum fitness of a chromosome after required number of generations is: 0.805 The network load for establishing 10 lightpaths is: 02 The total delay in establishing all the lightpaths is: 421 The maximum hops traversed by a lightpath: 06 The number of fibers used to honor all the lightpaths: 18 The maximum delay of a lightpath: 83

We further extended the simulation work to accommodate different sets of source-destination pairs and to establish lightpaths for these node pairs using both single objective and multi objective GA. The ability of both types of GAs are compared as they optimize various network parameters while establishing lightpaths for different sets of source-destination pairs and depicted in Fig. 5, Fig. 6, Fig. 7, Fig. 8 and Fig. 9 .

VII. Conclusion

We conclude that the overall performance of multi objective genetic algorithm is better than single objective genetic algorithm in optimizing different network parameters such as total set up time of all lightpaths, the maximum set up time of a lightpath in a given demand set, the maximum number of hops traversed by a lightpath in a given demand set and the number of fibers used to establish all the connection requests. However, an alteration is shown in their performances while optimizing the total connection set up time for distinct sets of 30 and 40 lightpath requests. In Fig. 10, we have compared the execution time between single objective and multi objective GA to take the routing decision for all the lightpath requests and the analysis reveals that multi objective GA obtains better results with almost the same execution time as that of single objective GA.

VIII. Future work

In the current work, our primary optimization objective to implement a multi objective GA was based on reducing the congestion of the most congested link. We can modify this design formulation by considering other RWA objectives and test run the multi objective GA under different fitness functions. The primary design objectives considered for stating other fitness functions are enumerated as follows:

- Reducing the difference between most and least congested link in the network:

$$y4 = 1 - 0.90\frac{con-l\_con}{|K|} - 0.07\frac{tot\_r\_length}{d|K|(|V|-1)} - 0.01\frac{\max\_r\_length}{d(|V|-1)} - 0.01\frac{\max\_h\_count}{|V|-1} - 0.01\frac{tot\_fib}{|E|} \quad (29)$$

- Reducing the difference between most congested link and average congestion of all links in the network:

$$y4 = 1 - 0.90\frac{con-a\_con}{|K|} - 0.07\frac{tot\_r\_length}{d|K|(|V|-1)} - 0.01\frac{\max\_r\_length}{d(|V|-1)} - 0.01\frac{\max\_h\_count}{|V|-1} - 0.01\frac{tot\_fib}{|E|} \quad (30)$$

The symbols have their usual meanings as defined earlier except the newly introduced ones which are defined below:

- l_con= Congestion level of the least congested link in the network
- a_con= Average congestion of all links in the network

Furthermore, the fitness function modeled in this work can be modified to apply it in wavelength convertible networks. Fairness among connection requests is another issue that deserves more investigation in future.

Acknowledgment

This research is supported by SERC, DST, Government of India and monitored by Centre for Soft computing Research: A National Facility, ISI, Kolkata with the title as Soft computing techniques to solve Routing and Wavelength Assignment (RWA) problem in optical network and carried out at department of Computer Science & Engineering, NIT Rourkela.

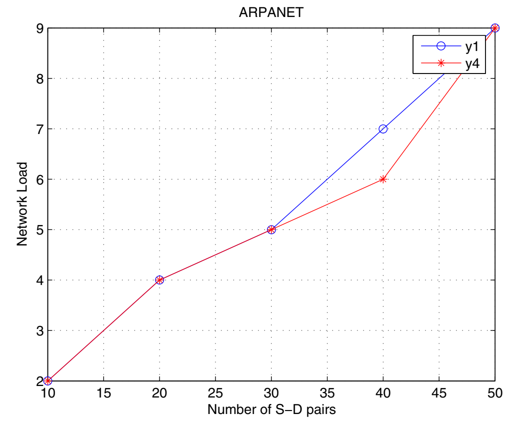

Fig. 5: Optimizing the network load

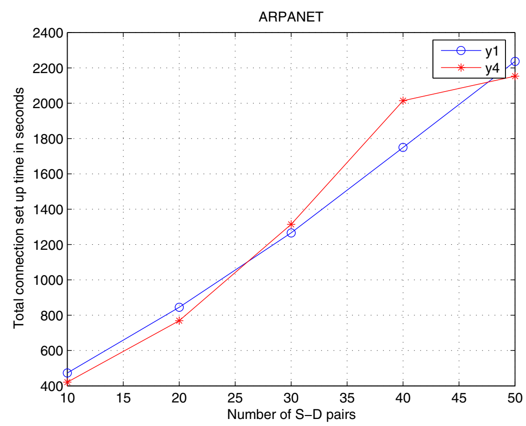

Fig. 6: Optimizing the total set up time of all lightpaths

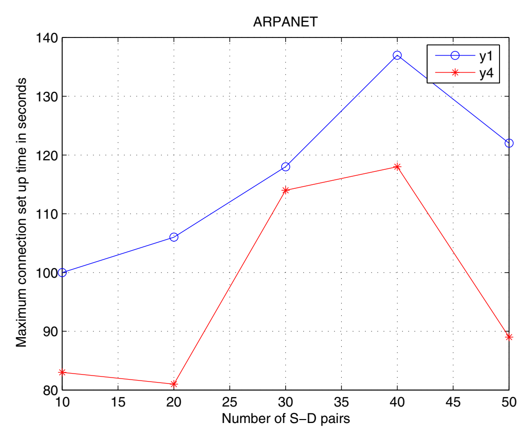

Fig. 7: Optimizing the maximum connection set up time

References

[1] I. H. Peng, "Study of Effective Resource Allocation Schemes in WDM Networks," Ph.D. dissertation, 2008, thesis.lib.ncu.edu.tw.

[2] S. Ishida, "A Study on Flexible, Reliable, and Scalable Wavelength-Routed Optical Networks," Ph.D. dissertation, Department of Information Networking, Graduate School of Information Science and Technology, Osaka University, February 2007.

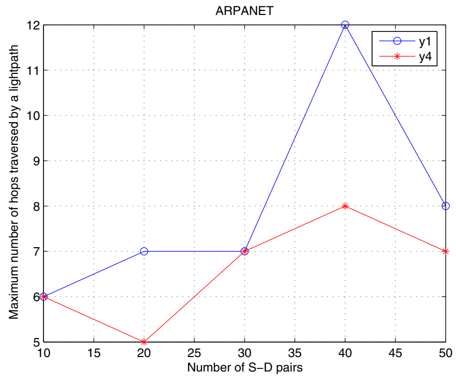

Fig. 8: Optimizing the maximum number of hops traversed by a lightpath

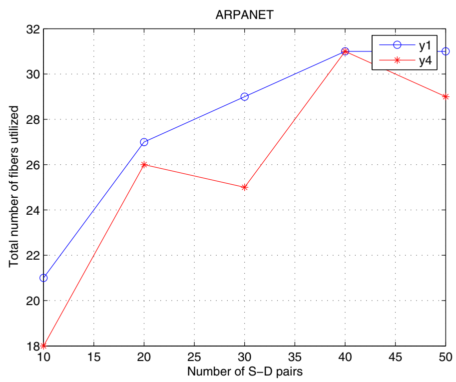

Fig. 9: Optimizing the total number of fibers utilized

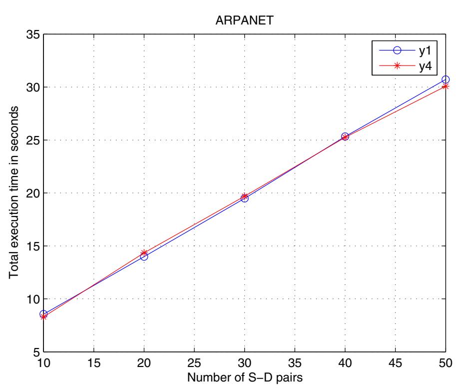

Fig. 10: Comparison of execution time

[3] B. Mukherjee, *Optical Communication Network*. New York: Mc-Graw Hill, 1997.

[4] R. Ramaswami, K. Sivarajan, and G. Sasaki, *Optical Networks: A Practical Perspective*, 3rd ed. Morgan Kaufmann.

[5] B. Mukherjee, *Optical WDM Networks*. Springer, January 2006.

[6] ——, "WDM optical networks: progress and challenges," *IEEE Journal on Selected Areas in Communications*, vol. 18, no. 10, pp. 1810–1824, October 2000.

[7] S. H. Ngo, "Ant-Based Mobile Agent Approach for Dynamic Routing and Wavelength Assignment in WDM Optical Networks," Ph.D. dissertation, School of Information Science, Japan Advanced Institute of Science and Technology, September 2006.

[8] C. V. Saradhi, M. Gurusamy, and L. Zhou, "Differentiated Qos for survivable WDM optical networks," *IEEE Communication Magazine*, vol. 42, no. 5, pp. S8–14, 2004.

[9] J. L. Kenningtona, E. V. Olinick, and G. Spiride, "Basic mathematical programming models for capacity allocation in mesh-based survivable networks," *International Journal of Management Science*, pp. 1–16, 2006.

[10] Y. S. Kavian, H. F. Rashvand, W. Ren, M. S. Leeson, E. L. Hines, and M. Naderi, "Rwa problem for designing dwdm networks- delay against capacity optimization," *IEEE Electronics Letters*, vol. 43, no. 16, August 2007.

[11] R. Datta, S. Ghose, and I. Sengupta, "A rerouting technique with minimum traffic disruption for dynamic traffic in wdm networks," in *11th IEEE International Conference on Networks*, Sydney, Australia, September 28-October 1 2003.

[12] ——, "New schemes for connection establishment in gmpls environment for wdm networks," *International Journal on Wireless and Optical Communication*, vol. 2, no. 1, June 2004.

[13] I. Chlamtac, A. Ganz, and G. Karmi, "Lightpath Communications: An Approach to High Bandwidth Optical WANs," *IEEE Transactions on Communications*, vol. 40, pp. 1171–1182, 1992.

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

[15] H. 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, January 2000.

[16] D. P. LEA, "Soft computing approaches to Routing and Wavelength Assignment in wavelength-routed optical networks," Ph.D. dissertation, North Carolina State University, 2004.

[17] 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.

[18] R. Ramaswami and K. N. Sivarajan, "Design of Logical Topologies for Wavelength- Routed Optical Networks," *IEEE Journal on selected areas in Communication*, vol. 14, no. 5, pp. 840–851, 1996.

[19] R. G. Michael and D. S. Johnson, *Computers and Intractability: A Guide to the Theory of NP Completeness*. San Francisco, CA: W. H. Freeman and Company, 1979.

[20] H. Qin, Z. Liu, S. Zhang, and A. Wen, "Routing and Wavelength Assignment based on Genetic Algorithm," *IEEE Communication Letters*, vol. 6, no. 10, pp. 455–457, 2002.

[21] 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, February 1999.

[22] M. Sinclair, "Operator-Probability Adaptation in a Genetic-Algorithm/Heuristic Hybrid for Optical Network Wavelength Allocation," in *IEEE International Conference on Evolutionary Computation*, 1998, pp. 840–845.

[23] Z. Pan, "Genetic Algorithm for Routing and Wavelength Assignment Problem in All-optical Networks," Depatrment of Electrical and Computer Engineering, University of California, Davis, Tech. Rep., 2002.

[24] D. Bisbal, I. D. Miguel, F. Gonzalez, J. Blas, J. C. Aguado, P. Fernandez, J. Duran, and M. Lopez, "Dynamic Routing and Wavelength Assignment in Optical Networks by means of Genetics Algorithms," *Photonic Networks Communications*, vol. 7, no. 1, pp. 43–58, 2004.

[25] 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, October 1995.

[26] R. Krishnaswami and K. Sivarajan, "Algorithms for routing and wavelength assignment based on solution of LP-relaxations," *IEEE Communication Letter*, vol. 5, pp. 435–437, October 2001.

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

[28] Z. Michalewicz, *Genetic Algorithms + Data Structure = Evolution Programs*, third rev. and extended ed. ed., 1996.

[29] L. D. Davis and M. Mitchell, "Handbook of Genetic Algorithms," *Van Nostrand Reinhold*, 1991.

[30] C. W. Ahn and R. S. Ramakrishna, "A GA for shortest path routing problem and the sizing of populations," *IEEE Transaction on Evolutionary Computing*, vol. 6, no. 6, pp. 566–579, 2002.