"Study of Routing and Wavelength Assignment problem and Performance Analysis of Genetic Algorithm for All-Optical Networks"

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Darshan Gourkar

Roll Number – 10606042

Department of Computer Science and Engineering

National Institute of Technology

Rourkela

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Darshan Gourkar

Roll No. - 10606042

ABSTRACT

All-optical networks uses the concept of wavelength division multiplexing (WDM). The problem of routing and wavelength assignment (RWA) is critically important for increasing the efficiency of wavelength routed All-optical networks. For the given set of connections, the task of setting up lightpaths by routing and assigning a wavelength to each connection is called routing and wavelength allocation problem. In work to date, the problem has been formulated as integer linear programming problem. There are two variations of the problem: static and dynamic, in the static case, the traffic is known where as in dynamic case, connection request arrive in some random fashion. Here we adopt the static view of the problem. We have studied the Genetic Algorithm to solve the RWA problem and also we studied a modified Genetic Algorithm with reference to the basic model. We studied a novel opimization problem formulations that offer the promise of radical improvements over the existing methods. We adopt a static view of the problem and saw new integer- linear programming formulations, which can be addressed with highly efficient linear programming methods and yield optimal or near-optimal RWA policies. All-optical WDM networks are chracterized by multiple metrics (hop-count, cost, delay), but generally routing protocols only optimize one metric, using some variant shortest path algorithm (e.g., the Dijkstra, all-pairs and Bellman-ford algorithms). The multicriteria RWA problem has been solved combining the relevant metrics or objective functions. The performance of RWA algorithms have been studied across the different standard networks. 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. It has been observed that the modified genetic algorithm performed better than the existing algorithm with respect to the time and cost parameters.

INTRODUCTION

The wavelength division multiplexing (WDM) is one of the best techniques which serves for the future all-optical networks [7]. Wavelength division multiplexing and wavelength routing are rapidly becoming the technologies-of-choice in network infrastructure to meet the tremendous bandwidth demand of the new millennium. They are also receiving increasing attention from the telecommunications industry. In WDM an optical fiber link carries several optical signals using different wavelengths.The capacity of such fiber links are huge in terabits per second. The physical limitations of the optical medium and the cost and complexity of the optical switching need to be acounted for in this design. A particularly important consideration in this context is number of wavelengths associated with an optical link i.e. the number of separate wavelengths that can be supported in that link. The network is wavelength continous such that the same wavelength must be used throughout the lightpath [5],[6].

The optical signals which are carried on the optical fiber are processed at low electronic speeds. Thus, these signals must be converted into the electronic signals, and after processing it again converted back to the optical signals for the transmission over optical fiber. This electro-optic conversion needed to facilitate electronic processing which is also expensive. The 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.[5]

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 [5].

 We have studied the genetic algorithm for routing and wavelength allocation in all-optical networks with static configuration of the network. During the actual operation of the network, the traffic load offered to the network and the active source – destination node pairs may change dynamically. As a routing and wavelength allocation problem is a kind of exhaustive search technique, it is expected that the genetic algorithm will give better results than others. The problem is formulated using integer linear programming technique[1].

There has been great interest in WDM networks consisting of wavelength routing nodes interconnected by the optical fibers [5]. Such networks carry data between access stations in the optical domain without any intermediate optical to/from electronic conversion. To be able to send data from one access node to another, one needs to establish a connection in the optical layer similar to the one in circuit-switched network. This can be realized by determining a path in the network between the two nodes and allocating a free wavelength on all of the links on the path. Such an all-optical path is commonly refered to as a lightpath and may span multiple fiber links without any intermediate eleatronic processing, while using one WDM channel per link. The entire bandwidth on the lightpath is reserved for this connection until it is terminated, at which time he associated wavelengths become available on all the links along the route [5],[7].

In the absence of the wavelength conversion, it is required that the lightpath occupy the same wavelengths over all the fiber links it uses. This requirement is referred to as the wavelength continuity constraint. However, this may results in the inefficient utilization of WDM channels. Aternatively, the routing nodes may have limited or full conversion capability, whereby it is possible to convert an input wavelength to a subnet of the available wavelengths in the network [1].

Since lightpaths are the basic building blocks of this network architecture, their effective establishment is crucial. Therefore, it is important to provide routes to the lightpath requests and assign wavelengths on each of the links along this route among the possible choices so as to optimize the certain performance metric. This is known as routing and wavelength assignment problem. The wavelength assigned must be such that no two lightpaths that share a physical link use the same wavelength on that link [5]. Moreover, in the networks without wavelength converters, the same wavelength must be used on all links of the lightpath (wavelength continuity constraint). The RWA problem is critically important in increasing the efficiency of the wavelength-routed optical networks. With a good solution of this problem, more customers can be accomodated by the given system, and fewer customers need to be rejected during periods of congestion [1].

Numurous research studies have been conducted on the RWA problem. Several RWA schemes have been proposed that differ in the assumptions on the traffic pattern, availability of the wavelength convertors, and desired objectives. The

traffic assumptions generally fall into one of two catogories: static or dynamic [1],[5]. The objective in the static case is typically to accommodate the demand while minimizing the number of wavelengths used on all link. On the contrast in the dyanamic setting the objective is to minimize the call blocking probability, or the total number of blocked calls over a given period of time [1].

In the static case, typical proposed formulations for optimal lightpath establishment turn out to be difficult mixed integer linear programes[1]. In particular, the optimal static lightpath establishment problem without wavelength convertors was proven to be NP-complete by showing the equivalence of the problem to the graph-coloring problem [8]. Since the associated integer linear programs are very hard to solve, the corresponding relaxed linear programs have been used to get bounds on the desired objective function. Alternatve formulations have been considered to get tighter bound. These bounds are used as benchmarks against which performance of various heuristic RWA algorithms can be compared [3].

Due to the computational complexity in obtaining an optimal solution, much of the previous work on the RWA problem has focused on developing efficient heuristic methods. A common approach is to decouple the RWA steps by first finding a route from the predetermined set of candidate paths and then search for the appropriate wavelength assignment [3], [9]. However, given that the number of wavelengths is restricted, a common wavelength may not be available on all the links along a chosen route. Thus, RWA should be considered jointly for the best performance.

A lot of recent work in WDM networks is based on the maximum load model. The route of each request is given and the problem is to find the minimum number of wavelengths to satisfy a given request set. This is the worst case model, where no blocking of lightpath is allowed, and there are no assumptions are made on the traffic pattern. The traffic is characterized only by its load, which is the maximum number of lightpaths that can be present over any link of the network [2],[9],[10]. However, this results in overdesigning the networkand using many wavelengths to support a typical request patterns.

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 nodes pairs may change dynamicall. 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 studied the algorithms that can be used to handle routing and wavelength allocation with less number of wavelengths.

Routing and Wavelength Allocation (RWA) problem

In the WDM networks, there is a tight coupling between routing and wavelength selection [5]. Selecting a path of links between the source and destination nodes, and reserving a particular wavelength on each of these links for the lightpath implement a lightpath. Thus for establishing an optical connection we have to select a suitable path and allocate an available wavelength for the connection. The resulting problem is called routing and wavelength allocation (RWA) problem. The routing and wavelength allocation problem is subject to the following two constraints: Wavelength continuity constarint and Distinct wavelength constraint [4].

There are two variations in the problem [5]:

1) Static RWA: The traffic requirements are known in advance.

2) Dynamic RWA: The sequence of lightpath requests arrive in some random fashion.

The static RWA problem in all-optical networks can be decomposed into four subproblems [5]:

1) Topology Subproblem: Determine the logical topology which is to be imposed on the physical topology, i.e. determine the lightpaths in terms of there source and destination edge nodes.

2) Lightpath Routing Subproblem: determine the links, which each lightpath consists of, i.e. route the lightpath over the physical topology.

3) Wavelength Allocation Subproblem: Allocate a wavelength to each lightpath in te logical topology so that wavelength restrictions are obeyed for each physical link.

4) *Traffic Rrouting Subproblem:* Route packet traffic between source and destination edge nodes over the logical topology obtained.

Most of the literature on the RWA problem considers either networks without any wavelength convertors or networks with the wavelength convertors at every node. The benefits of the wavelength conversion have been analyzed under different traffic models [10],[11]. However, the high cost of the full wavelength conversion at every node had led to some research on the networks with sparse wavelength conversion [2],[3],[10]. In such a networr, only the fraction of the nodes are equipped with the wavelength convertors. We assume that we have full wavelength conversion capability at the nodes where there are the wavelength convertors. The blocking performance of such a network has been analyzed in assuming a statistical traffic model and a simple routing-wavelength allocation scheme.

There has also been considerable interest in obtaining the call blocking performance of wavelength-routed networks under dynamic trafic assumptions [3],[10],[12] . For this purpose, stochastic models are employed for the call arrivals and service times. The performance of the network is studied when some simple routing-wavelength allocation methods are used. The main goal in these studies is to identify important network parameters that effect the blocking performance of the network.

Here, we have studied an efficient algorithmic approach for optimal RWA for optical networks. Our approach can be used for networks with no wavelength conversion and easily extends to networks with sparse wavelength conversion. In a general formulation, we may consider a dynamic and stochastically varying demand model, where it is important that present-time decisions take into account the effect of the uncertain future demand and unavailability of resources. This formulation leads to dynamic programming problem, which are difficult to solve optimally. We therefore, study a static view of the problem, based on optimal multicommodity routing, which is closer to the currently existing approaches. However, we take into account the effect of the present-time decisions on future resource availability by means of a cost function which tends to leave room for future lightpath establishments.

The key new aspect of our formulation that sets it apart from other approaches, is that mainly because of the structure of the cost function, the resulting formulation tends to have an integer optimal solution even when the integrality constraints are relaxed, thereby allowing the problem to be solved optimallyby fast and highly efficient linear programming methods[1]. Because of the optimality of the solution produced, our methodology is not subject to the performance degradation that is inherent in the alternative heuristic approaches. We prove the optimality of the resulting solutions in a special but widely used in the practice topologies, such as ring networks under some assumptions. For the case when our approaches fails to find the integer optimal solution for arbitrary network topologies that has full wavelength conversion for that we provide the efficient rounding method. This method takes into account the structure of the cost function, and starting from an optimal non integer solution, produces a possibly sub-optimal integer solution. It may also be used to construct efficient methods that find optimal or near-optimal solutions for the no wavelength conversion case. However, based on our ring network analysis, as well as extensive computational experimentation, it is likely that an integer optimal solution can be found by our methodology for the most optical networks and traffic patterns encountered in the practice.

Mathematical Model of RWA

Integer Linear Programming Approach:

We have studied the routing and wavelength assignment problems jointly for the optical network. At the first step we are given a set of lightpath requests to be established for the static traffic. Lightpath request may be terminated randomly. Now we have to assign routes and wavelengths to the new requests without rerouting the existing lightpaths. Since the number of wavelengths is limited, statistacally, some of the lightpath requests will be blocked. Now our goal is to minimize the expected value of the sum of the blocking costs. This problem is called the dynamic programming problem [1], which models the stochastic nature of future lightpath arrivals or departures.

The optimization variables of the dynamic programming problem are the RWA decisions to be made each time there is a new lightpath request [3]. The state of the system is the set of established lightpath requests plus the new lightath requests, and the new state is changed based on the corresponding RWA decision. A cost is incurred each time a lightpath request must be blocked due to the wavelength unavailability. Unfortunately, the state space for this dynamic programming problem is prohibitvely large. While it is possible to address the computational difficulty approimations. Although more static in character, this approach still addresses to some extent the dynamic nature of the problem by spreading the traffic in such a way that no link is operated close to its capacity [1],[6].

Our new approach is a type of optimal multicommodity flow formulation. Multicommodity network f low problems involve several flow types or commodities, which simultanously use the network and are coupled through either link capacities or through the cost function.

In the context of optical networks, different commodities correspond to different lightpaths to be established between nodes of the network. Let us first focus on the simple case wherewe have full wavelength conversion at all the routing node. For these networks, there is no distinction between the available wavelengths, i.e., the wavelength continuity constraint need not be satisfied along the lightpaths and the

number of wavelengths on each link merely specifies a capacity constraint on the total number of lightpaths that can cross that link [6]. Hence, these networks are mathematically are no different no different than a circuit-switched network. The optimal RWA problem for such networks reduces to finding a route for each lightpath(without assigning a specific wavelength) such that the reslting flows satisfy the capacity constraints. For optical networks, flow is actually measured in terms of the lightpaths that cross that link and flow of a path corresponds to the no. of lightpaths that use that path [1].

Formulation into ILP :

We can formulate the RWA problem into an Integer Linear Programming problem for the single fiber networks assuming that the wavelength continuity constraint is satisfied [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 of 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 wavelength $w \in W$ that is assigned to every link on p; which ensures wavelength continuity constraint. The pair (p, w) 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 wavelengths and maximize the number of lightpath requests realized.

Let x(p,w) denote the number of lightpaths successfully routed over physical path $p \in P$ and assigned wavelength $w \in W$. The RWA problem can be cast as ILP as follows [5]:

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

subject to:

1) Distinct wavelength constraint:

$$\sum_{p=P(e)} x(p,\omega) \leq 1, \forall e, \omega$$

2) Number of wavelengths established doesnot exceed the number of requests.

$$\sum_{\omega \in W} \sum_{p \in P(s,d)} x(p,\omega) \leq r_{sd}, \forall s, d$$

$$where \quad x(p,\omega) \geq 0, \quad integer, \forall p, \omega$$

In the above formulation, the overall cost function is given by the sum of link cost functions and each of the link cost functions depends on the amount of flow on the link. For this problem, we choose the link cost functions to have the piecewise linear form. The cost function has two key features that impact significantly on the nature of the optimal solution [1].

a) The cost function of every link is convex, monotonically increasing, and piecewise linear. Thus, the marginal cost for routing a new lightpath over a given link is larger than the marginal cost for routing the preceding lightpaths on the same link.

b) The breakpoints of each piecewise linear link cost function occur at the integer points $0,1,\ldots,|C|$. The cost for flow larger than $|C|$ is ∞., thereby imposing a link capacity constraint.

Because of feature a), the resulting optimal solution of the associated linear program, favours choosing paths with underutilized links; and tends to leave room for the future lightpaths. Because of feature b), the resulting optimal solution tends to be integer, as thereby, obviating the need for time-consuming integer programming techniques [1].

In the optical networks with no wavelength conversion, the above path flow formulation needs to be modified because of the wavelength continuity constraint that needs to be satisfied along the lightpaths. For such networks, the path flows need to be distinguished by wavelength/color as well [1],[6].

Obtaining integer solution

The use of the piecewise linear objective function D_l with integer break points has some inportant consequences [2]:

1) The coresponding relaxed linear pogramming model, where the integer constraints are replaced by the relaxed constraints, can be solved by efficient commercial or special purpose simplex methods with fast running times.

2) Even, if we relax the integer constraints, it appears that the integer optimal solution can still be obtained in most cases of interest.

We have studied Analysis and Computational experiment using a simplex code. After experimenting with a few general mesh networks of moderate size (five to ten nodes), we focused on ring networks. We used a random problem generation method, whereby each node of the ring is the origin with the predetermined probability 'p' and sends one unit of flow to randomly selected destination. We have tried many such randomly generated problems involving n-node rings with n=8, 10, 15. The resulting solution turned out to be integer in all cases. We have also proved the integrality of optimal solutions analytically for the case of general ring networks with multiple origins and destinations under some asumptions.

Thus, our observations indicates that for most of the cases, the relaxed problem, in any of the given formulations, has an integer optimal solution. The reason is that, because of the structure of the piecewise linear cost function, extreme points of the relaxed constraints polyhedron appear to be integer in majority of the cases [1]. Inutiatively, the extreme points of the constraint set tnd to correspond to the corner points of the piecewise linear objective function, which take integer values.

Finally, we mention that even in the cases where the solution to the relaxed problem may be fractional, the number of fractional variables in the solution typially turn out to be insignificant relative to the number of integer variables [1],[3],[7]. As a result, it may be possible to round the fractonal portion of the solution to integer with the use of simple heuristics. Indeed, we provide a simple rounding method that takes into account the structure of the cost function, and starting from a fractional optimal solution, produces an integer solution with no or little loss of optimality.

Genetic Algorithm for RWA problem

The main objective of this RWA problem is to find the route for each lightpath (s_i, d_i) to minimize the number of wavelengths needed, and also include the secondary targets to minimize the total cost and to minmize the maximum cost of a lightpath [5].

To achieve this the following **assumptions** are made:

1) Network is static and circuit switched.

2) The wavelength continuity constraint is satisfied.

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 [5]:

1) Pop: the number of chromosomes in a generation. A large pop is necessary to maintain good diversity.

2) Gen_max: The maximum number of generations to run.

3) Mrate: The probability of performing mutation operation on the new generation chromosome.

4) Crate: The probability a selected new generation chromosome undergoes crossover.

5) Mratio: The percentage of lightpaths in a selected chromosome will be modified in a mutation operation.

6) Cratio: The percentage of lightpaths in a selected chromosome will be modified in a crossover operation.

Structure of a Chromosome: The chromosome is a group of vectors P. Each vector $P_i = [n_{i0}, n_{i1}, ..., n_{ih}]$ is the route of the lightpath (s_i, d_i). So, each chromosome 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 nembers of nodes in the network G instead binary strings to avoid the difficulty in implementation of operations [5].

Selection of fitness funcion: Fitness function can be considered as the target function to be maximized [1],[5]. For the routing, the fitness function can be defined as:

$$y = 1 - 0.9 \frac{overlaps}{N_i} - 0.08 \frac{totalcost}{N_i(N_i - 1)\,max\,link\,cost} - 0.02 \frac{max\,path\,cost}{(N-1)\,max\,link\,cost}$$

Where,

    N_i: Number of lightpaths

    N: Number of nodes

    Maxlnkcost is the maximum cost of a fiber link in the network.

The fitness function is composed three main items, each is divided by its maximum possible value, and each describes a metric that needs to be minimized [5]:

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 lighpaths. It is desired to minimize this value.

3) Maxpathcost: the max cost of a lightpath. It is also desired to minimize this value.

Genetic Algoithm : (GA-1)

This below mentioned genetic algorithm is proposed by Zhong Pan [13].

Step 1: Obtain the costs of links in network G.

Step 2: 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 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, i.e. 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:

$$y = 1 - 0.9 \frac{overlaps}{N_i} - 0.08 \frac{totalcost}{N_i(N_i - 1)\,max\,link\,cost} - 0.02 \frac{max\,path\,cost}{(N - 1)\,max\,link\,cost}$$

where,

N_i is the number of links in the lightpath.

Step 4: Selection of the 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:

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

2) 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.

$$probab_i = \frac{fitness_i}{\sum_i fitness_i}$$

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

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

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

In this 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 lightpath P_i, randomly pick two nodes n_{ij} and n_{ik}. Remove all the nodes n_{ij} such that $i<j$ or $i>k$. 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.

Modified Genetic Algorithm [5]: (GA-2)

The following modification has done by Kundurthy Sujatha and Bibhudatta Sahoo in their paper published in Nov,2006.

In the above algorithm, the following changes are proposed in order to increase its performance [5]. 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:

$$y = 1 - 0.9 \frac{overlaps}{N_i} - 0.08 \frac{total\,cost}{N_i\,(N_i - 1)\,max\,link\,cost} - 0.02 \frac{max\,path\,cost}{(N-1)\,max\,link\,cost} - 0.01 \frac{hopcount}{N-1}$$

new parameter, hopcount can be defined as the number of hops taken by each lightpath [5].

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, either probability crate a chromosome is crossover with another randomly picked chromosome. The crossover operation defined in this algorithm is:

6.1 According to crate, 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.

RESULTS

The algorithms GA-1 and GA-2 are studied and observations are taken for ARPANET, and NSFNET [5]. The results are taken for different sets of lightpath requests.

Results with ARPANET:

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

From the results, it has also shown that the GA-1 and GA-2 take unstable costs of the paths for the less number lightpath requests for ARPANET . The total cost of paths calculated under modified approach is performing better than the original one proposed by Zhong Pan , when there are more number of lightpath requests are present.

The observations are taken from the paper presented by Zhong Pan [13].

For GA-1 proposed by Zhong Pan:							
Lightpath 10 to 13:		10	19	20	17	13	
Lightpath 15 to 7:		15	16	19	10	7	
Lightpath 7 to 4:		7	3	1	2	5	4
Lightpath 10 to 1:		10	7	3	1		
Lightpath 15 to 14:		15	14				
lightpath 10 to 8:		10	8				
Lightpath 8 to 15:		8	12	18	16	15	
lightpath 2 to 10		2	4	11	9	10	
Lightpath 3 to 9		3	8	9			
Lightpath 9 to 20:		9	8	12	14	20	
Maximum fitness= 0.808289							
Number of wavelengths required = 2							
Total cost = 490.000000							
Maximum path cost= 101.000000							
The algorithm took 12.200000 seconds to run.							

The observations are taken from the paper presented by K. Sujatha and Bibhudatta Sahoo on Nov.,2006 [5].

| For GA-2 Algorithm proposed by K. Sujatha:							
Lightpath 10 to 13:		10	19	20	17	13	
Lightpath 15 to 7:		15	16	19	10	7	
Lightpath 7 to 4:		7	3	1	2	5	4
Lightpath 10 to 1 :		10	7	3	1		
Lightpath 15 to 14:		15	14				
Lightpath 10 to 8 :		10	8				
Lightpath 8 to 15:		8	12	14	15		
Lightpath 2 to 10:		2	4	11	9	10	
Lightpath 3 to 9:		3	8	9			
Lightpath 9 to 20:		9	8	12	14	20	
maximum fitness= 0.807526							
Number of wavelengths required = 2							
Total Cost = 468.000000							
Maximum path cost = 96.000000							
The algorithm took 12.100000 seconds to run.							
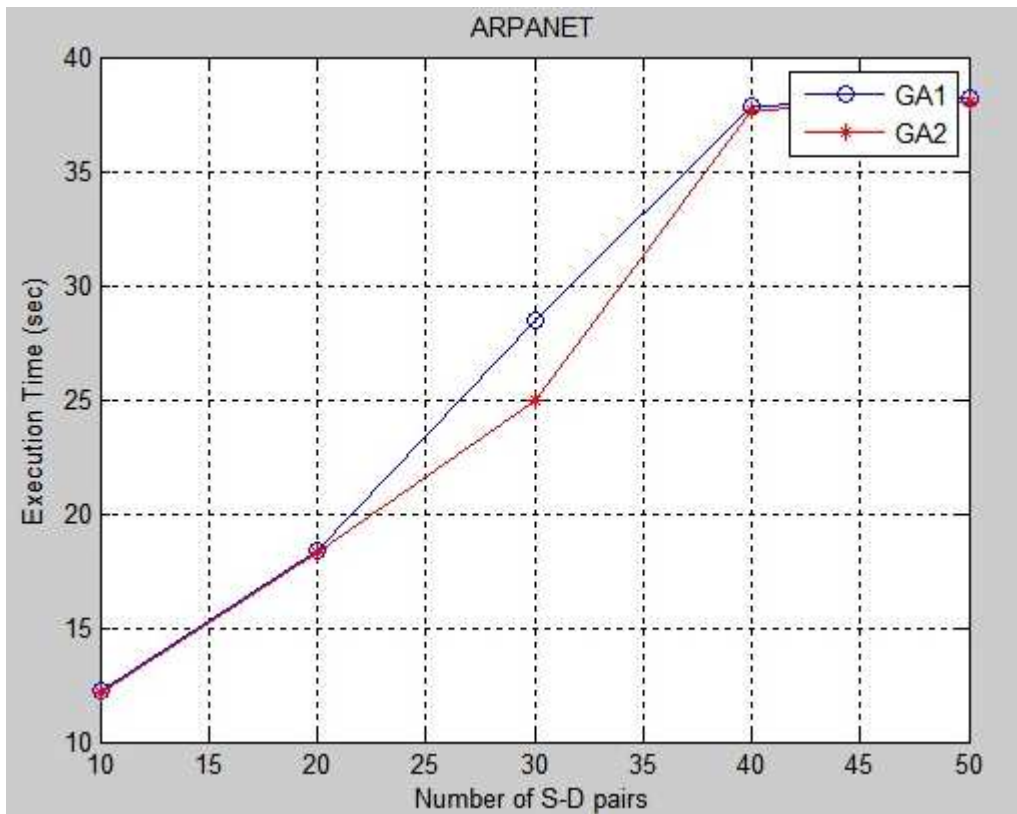
Fig.1: Simulation results on the performance of original algorithm and modified algorithm: Execution time of the routing Vs Number of S-D node pairs (lightpath requests) in ARPANET.

Results with NSFNET:

According to the observation, the GA-1 and GA-2 take almost same time for executing the routing decision for the less number lightpath requests. The GA-2 is performing better than GA-1, when there are many number of lightpath requests are present.

It can be observed that 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.

The observations are taken form paper presented by Zhong Pan [13]:

For GA-1 proposed by Zhong Pan:								
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						
Lightpth 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	
Lightpath 9 to 2:	9	8	14	16	5	2		

Maximum fitness = 0.803901
Number of wavelengths required = 2
Total cost = 176.210000
Max. path cost = 19.850000
The algorithm took 10.440000seconds to run.

The observations are taken from paper presented by K. Sujatha and Bibhudatta Sahoo on Nov.,2006:

| For GA-2 proposed by K. Sujatha:								
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	11						
Lightpath 14 to 8:	14	8						
Lightpath 8 to 11:	8	7	6	13	14	16	5	
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								
Total Cost = 162.870000								
Maximum path cost = 42.580000								
The algorithm took 10.340000seconds to run.								
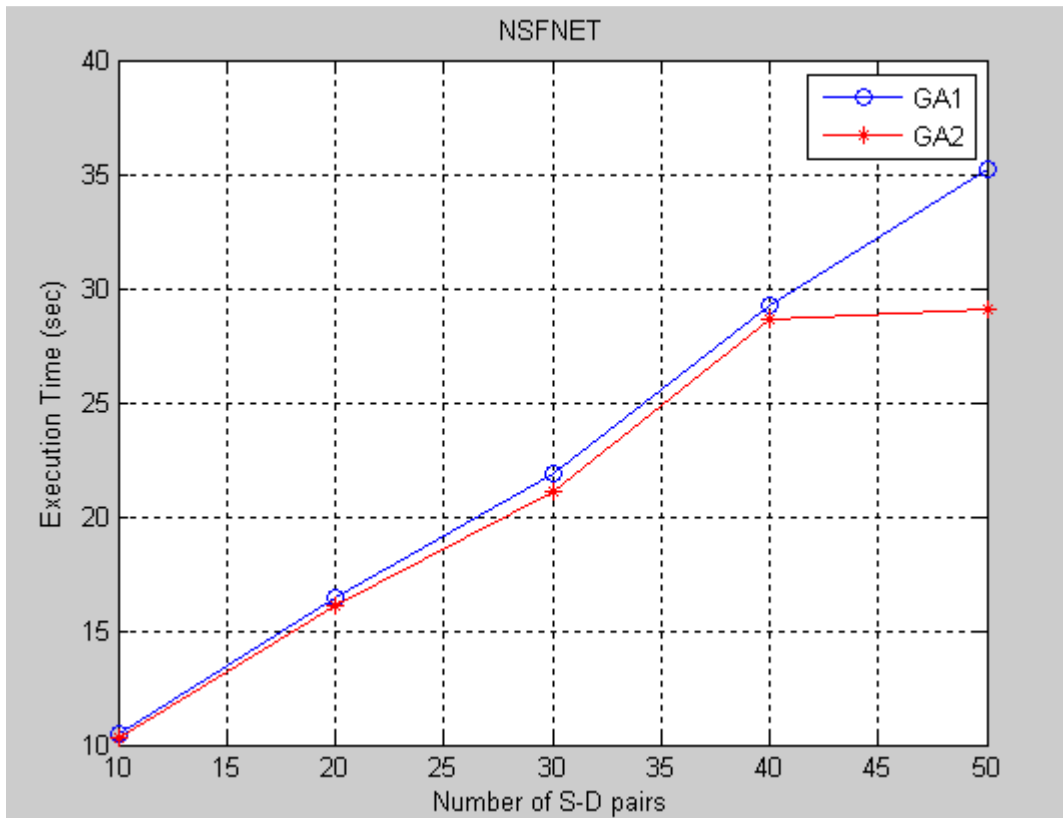
Fig.3: Simulation results on the performance of original algorithm and modified algorithm: Execution time of the Routing Vs Number of S-D node pairs in NSFNET.
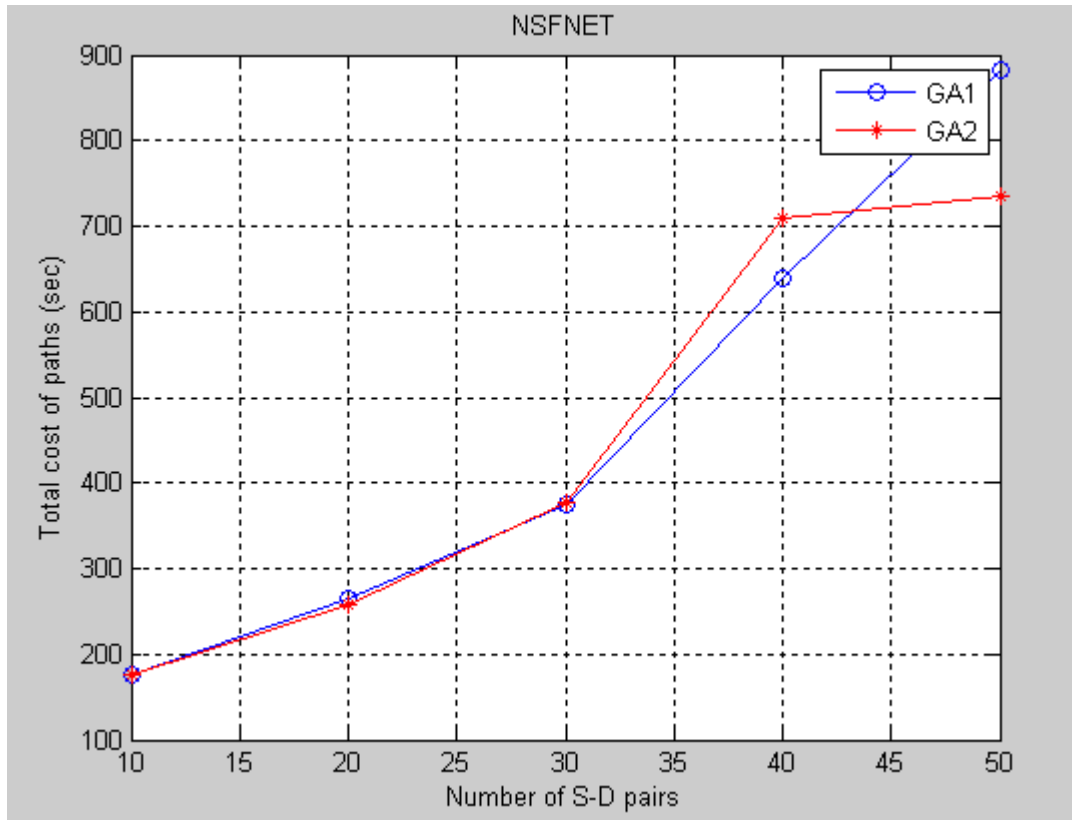
Fig.2: Simulation results on the performance of original algorithm and modified algorithm: Total cost of paths Vs Number of S-D node pairs (lightpath requests) in NSFNET.

CONCLUSION

The RWA problem in all-optical WDM networks is solved using the modified genetic algorithm which is found to be more optimal in terms of cost of the light-paths requested and time taken for routing decision making. We propose new integer linear programming formulations, which tend to have integer optimal solutions. The performance of modified algorithm has been compared with that of original one . 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.

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