

Review of routing and wavelength assignment problem

**Submitted by:
Birendra kumar**

109cs0641

Under the guidance of:

Prof. Ashok Kumar Turuk

Department of computer science & engineering

National Institute of Technology, Rourkela

Abstract

In today's internet world there is a growing demand of network bandwidth. Where traditional copper fibers offer very less bandwidth, optical fibers can offer very larger bandwidth. So, there is a growing sense of using optical fibers. Optical networks generally use wavelength division multiplexing (WDM) technique, which is the backbone of future generation internet. In WDM networks fibers are logically divided into non-interfering, circuit-switched communication channels.

In optical network Routing and Wavelength Assignment (RWA) problem is a typical problem. This can be seen as a conjunction of two problems, one is Routing and other one is Wavelength Assignment. First one finds a route from source to destination for requested connection and the next one assigns a wavelength to this route. The nature of RWA problem is NP-complete. Hence, heuristic approaches suits well for this class of problems.

RWA problem can be formulated as Integer linear programming (ILP) problem. This type of problem focuses on optimizing a single objective. Here objectives may be minimizing the number of amplifiers or maximizing the number of connections or minimizing the number of wavelength used. But our primary objective in RWA problem is to establish a loop free path which minimizes the crosstalk. To achieve this objective we are taking the help of genetic algorithm (GA). Congestion among the individual lightpath request will be the parameter for the application of genetic algorithm.

Content:

1. Abstract -----	2
2. Introduction-----	4
3. Routing and Wavelength Assignment problem-----	6
4. Motivation-----	7
5. Objective of the Research-----	8
6. Literature survey-----	9
7. RWA problem as NP-complete problem-----	11
8. The Genetic Algorithm based RWA algorithm-----	13
9. Simulation and results -----	15
10. Summary-----	19
11. Bibliography-----	20

2 .Introduction

Corning invented the first low-loss optical fiber in 1970. Now it is the worldwide market leader all network applications. Optical fiber plays an important role in information transmission. It has the advantages that facilitate the purpose of handling large volumes of Internet traffic as well as it meets the huge capacity requirement of advanced services such as voice chat, video streaming, P2P file sharing, grid computing, HDTV programming . Some of the advantages of optical fiber are listed as follows:

- ^ Optical fibers offer much higher bandwidth.
- ^ The transmission cost is considerably low.
- ^ Optical fibers are less susceptible to electro-magnetic interferences and other undesirable effects etc.

A single mode optical fiber has a bandwidth of about 25THz in the 1.55 micron low attenuation band. But demand for point to point communication per application is not that much. So, to utilize the full capabilities of optical networks, the bandwidth of an optical fiber is divided into multiple communication channels deploying WDM technology. Here, every channel corresponds to a unique wavelength.

Wavelength division multiplexing is obtained by dividing the low-loss regions of the optical transmission spectrum into several non-overlapping wavelengths. Each wave-length supports one communication channel which can be operated at a desired bit rate allowing multiple channels to coexist on a single fiber. It does not require nodes to synchronize to the same clock. One advantage of WDM is that no equipment needs to run faster than the bit rate of a single WDM channel, which

can be chosen arbitrarily. Therefore, WDM is the current favorite among multiplexing techniques for optical networks.

WDM is achieved by using optical receivers and transmitters at end nodes. Both lasers and light-emitting diodes serve as transmitters in optical networks. But, lasers are most widely used. Receivers separate out desired wave-lengths.

Routing is considered as a more practical architecture. The nodes in wavelengthrouted WDM networks are capable of routing wavelengths separately. Thus, it allows for reuse of wavelengths on routes that do not share common fiber. Therefore, this model is most suited for use in high speed next generation telecommunication networks.

3 .Routing and Wavelength Assignment problem

Routing and wavelength assignment problem is defined as follows:

We have given – 1.A network topology

2.Set of end-to-end light path requests

The problem of assigning a route and wavelength to these requests, using minimum possible wavelengths is known as the Routing and Wavelength Assignment (RWA) problem.

Because of the following two facts, complexity of RWA problem arises:-

1. Wavelength Distinct Constraint: On a given link two light path must not occupy the same wavelength.
2. Wavelength continuity constraint: On all the fiber link a light path must occupy the same wavelength.

There are two types of variant of RWA problem:

1.Static Light path Establishment (SLE) problem: Here, the entire set of connection requests is known in advance and the objective is to set lightpaths for these requests, at the same time minimize the number of wavelengths used. In other way, a static RWA algorithm tries to set up as many connection requests as possible given a fixed number of wavelengths per fiber link. The static RWA problem can be treated as an integer linear program which comes under the class of NP-hard problem.

2. Dynamic Light path Establishment (DLE) problem: Here, a light path is setup only by when a connection request arrives and it will be freed after some time.

4 .Motivation

Existing work suggest that, RWA problem mostly try to optimize a single objective function. These objectives minimizes one of the following:

- (i) the number of amplifiers
- (ii) network cost
- (iii) congestion
- (iv) maximize the number of connections satisfying the power constraints

But RWA problem can be modeled as bi-objective optimization problem. This can be solved using genetic algorithm. Here, the stated fitness function simultaneously involves the path length and the number of free wavelengths. Banerjee et al. have formulated the static RWA problem as a combinatorial optimization problem and solved it using GA.

The main challenge is that the formulated ILP should be able to establish a loop free light path that has shorter set-up time and lower congestion among the individual connection.

5 .Objective of the research

Following have been identifies as the objective of the research:

1. To interpret the RWA problem as an NP-complete problem
2. To model RWA problem as a multi-objective optimization problem.
3. Solve the above formulated ILP using genetic algorithm to optimize different network parameters under certain stated fitness functions and compare their results.

6 .Literature Survey

In this section we will give a brief survey of related work reported in the literature.

6.1 Heuristic Approaches for RWA Problem :

Chlamtac et. al. have given the concept of Lightnet architecture to deal with the problem of mismatch between the electronic processing rates and the optical transmission bandwidth in WDM based wide area networks. It works on the principle of construction and use of a virtual topology network in the wavelength domain. Their work focus on the embedding of virtual networks whose topologies are regular, using algorithms which provide bounds on the number of wavelengths, switch sizes, and average number of switching stages per packet transmission. Authors have shown that there is a substantial performance gains in comparison to conventional network architectures, in terms of increased throughput.

Banerjee et. al have considered the problem of designing a logical optical network topology for a given physical topology. Transmission between the end-users is carried in a packet-switched form and the objective of the logical topology design is to minimize the maximum congestion on the logical connections. They first gave a lower bound on the maximum congestion based on a linear programming formulation of the problem. Then they proposed an analytical model for obtaining the maximum and average logical connection loads in a logical network topology. The analytical model was confirmed by simulation results for many network configurations. Finally, they presented two design methodologies for obtaining logical topologies where the maximum link congestion is minimized. The first scheme maximizes total one-hop transmission at the same time maintaining connectivity of the topology by the use of a linear programming formulation. The second scheme starts with a completely connected topology and erases lightly loaded links until a topology with the desired nodal degree is found.

6.2 Meta-heuristic Approaches for RWA Problem

Authors have formulated the Static RWA problem in optical networks as a single objective optimization problem and solved it using an evolutionary algorithm. A hybrid approach based upon the k-shortest path for every source-destination pair is used to initialize the population. A special cost function based upon the frequency of occurrence of an edge in different source-destination paths is used to evaluate the fitness of chromosomes. Point crossover is used for maintaining the diversity in the solution space.

The wavelength assignment to lightpaths in fittest individuals is performed **1.** by a special graph coloring scheme.

The Max-RWA model is modified by introducing limited-range wavelength converters at the intermediate nodes. Here, the optimization objective is to maximize the establishment of connection requests with minimum use of wavelength converters. The Max-RWA problem is formulated as an ILP

2. problem which is then solved using genetic algorithm.

M. C. Sinclair gave a minimum cost wavelength-path routing and wavelength allocation scheme which uses genetic algorithm. A cost model that incorporates dependency on wavelength requirements and link has been adopted. The hybrid algorithm uses object-oriented representation of networks and includes four functions: single-point crossover, pathmutation, re-route and shift-out. After all, an operator probability adaptation mechanism is employed to improve operator productivity.

7 .RWA Problem is NP-Complete

NP class of problems have no deterministic polynomial time algorithms. These problems can be solved by a non-deterministic algorithm which is basically a definitional device for capturing the notion of verifiability, rather than a realistic method for solving the problems. NP problems are categorized into following classes; as per their complexity.

^ NP-hard: A problem is said to be NP-hard if an algorithm for solving it can be translated into one for solving any NP-problem. Therefore NP-hard means "at least as hard as any NP-problem," although it might be harder.

^ NP-complete: A problem L is said to be NP-complete if $L \in NP$ and for every $L' \in NP$;

To face with NP problems; below methods are generally adopted because the global optimum is unachievable in a feasible time :

^ Backtracking Dynamic, Programming or Branch-and-Bound techniques are generally used to reduce the computational cost of the problem solving.

^ The original problem is fractioned into sub-problems which have polynomial time solutions.

^ To find an approximate solution in polynomial time, approximation algorithms are used.

- ^ To find solution in given time with a very high probability of correctness of the solution, randomized algorithms are used.
- ^ Several heuristics like Simulated Annealing, greedy method, Genetic Algorithm etc. are often used to acquire solutions which are sure to be within a certain distance from the optimal solution.

When the fiber links of an optical network sustain enough wavelength channels; the RWA objective depends on minimizing the number of total wavelengths required to maintain all the light path requests. This is called Min-RWA problem. The time required to calculate the minimum number of wavelengths grows exponentially as the number of lightpath request grows. Hence , for larger instances of matrix, RWA problem becomes NP.

8 . The Genetic Algorithm Based RWA Algorithm

The genetic algorithm used to solve the formulated ILP is explained below:

- (i) **The Chromosome Structure:** We encode the chromosome as a vector of vectors
- (ii) **Initial Population:** For every lightpath, find the minimum cost path using Dijkstra's algorithm. For each fiber link in every light path disable one link at a time and find minimum cost paths to form a new chromosome. Repeat the above process until the population size is reached.
- (iii) **Fitness function:** The fitness function is the target function to be maximized and is used to discriminate the chromosomes such that better chromosomes will have better chance to propagate their genetic materials to the successive generations.
- (iv) **Selection of chromosomes for next generation:** The chromosomes of the next generation are selected from the current population through the spinning roulette wheel method.
- (v) **Crossover:** In the selected generation, with some crossover rate a chromosome is selected for mating with other chromosome. According to a crossover ratio, calculate the number of lightpaths is then calculated that will be modified. These lightpaths are then chosen randomly and these are then exchanged between the selected chromosomes.
- (vi) **Mutation:** In the selected generation, a chromosome is mutated with a fixed mutation rate. According to a mutation ratio, the number of lightpaths is calculated that will be modified. For each such lightpath $p_i = [n_{i0}; n_{i1}; \dots; n_{ij}; \dots; n_{i(j+1)}]$, randomly pick two adjacent nodes n_{ij} and $n_{i(j+1)}$. Disconnect the fiber link among two nodes and then 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 substitute the corresponding portion in p_i using the new path.

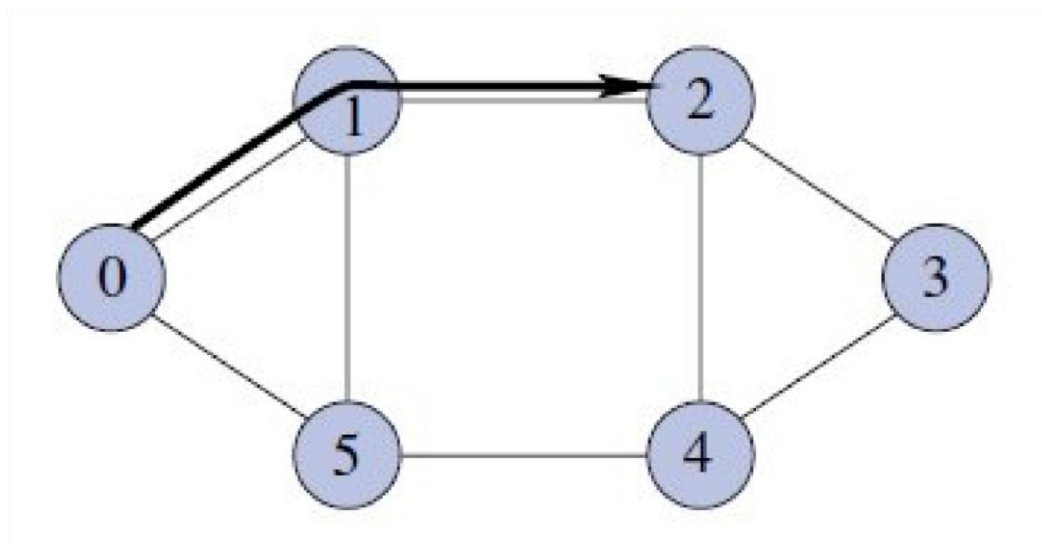
Selection schemes mainly predict the convergence characteristics of a Genetic Algorithm within a deterministic environment. The following effect of different genetic operators explain the convergence characteristics of the GA used to solve the formulated ILP:

- ^ Roulette spinning wheel selection drives the GA to improve the population fitness through upcoming generations. The statistical effect of roulette spinning wheel selection is: the best chromosomes get more copies, the average stay even and the worst dies.
- ^ The crossover operator causes the GA to converge on a nearly sub-optimal solution.
- ^ The mutation operator incorporates a random walk through the search space and avoid early convergence.

9 . Simulation and Result

Our simulation result will be based on a network which has 6 nodes and 8 links.

Considered network is shown below:



There is no limit on the number of wavelengths a fiber can carry; however an attempt is made to find the minimum possible number required to honor a given demand matrix.

Code:

```

clc;
clear;

maxgen=1000;
crpr=0.6;
popzs=4;

a=[1 0 0 1 0 0 0 0;0 1 0 0 1 1 0 0];
b=[1 0 0 0 0 0 0 0;0 1 1 0 0 0 0 0];
c=[0 0 0 1 0 0 0 1;0 0 1 0 1 0 1 0];
d=[0 0 0 0 0 0 0 1;0 0 0 0 0 1 1 0];
e=[0 1 0 0 0 0 0 0;1 0 1 0 0 0 0 0];
  
```

```

f=[0 0 0 0 0 0 1 0;0 0 0 0 0 1 0 1];
g=[0 0 0 0 1 0 1 0;0 0 0 0 1 1 0 1];
h=[0 1 0 0 1 0 0 0;1 0 1 0 1 0 0 0];

tic;
for i=1:popsz
j1=1+round(rand);
j2=1+round(rand);
j3=1+round(rand);
j4=1+round(rand);
j5=1+round(rand);
j6=1+round(rand);
j7=1+round(rand);
j8=1+round(rand);

population(:,i)=[a(j1,:);b(j2,:);c(j3,:);d(j4,:);e(j5,:);f(j6,:);g(j7,:);h(j8,:)];
end for j=1:maxgen tempop=population; newpop=population; p=1;
for pop=1:2:popsz k=rand; if k<crpr j9=1+round(rand*7);

tempop(j9+1:end, :, pop)=population(j9+1:end, :, pop+1);
tempop(j9+1:end, :, pop+1)=population(j9+1:end, :, pop);
newpop(:, :, popsiz+p)=tempop(:, :, pop); p=p+1;

newpop(:, :, popsiz+p)=tempop(:, :, pop+1);
p=p+1; end

end

[ row col rowa]=size(newpop);
f=zeros(rowa,1); for s=1:rowa
f(s)=max(sum(newpop(:, :, s)));
end

```



```
[ val ind]=sort(f); for u=1:popsz
population(:,u)=newpop(:,ind(u));

end
if j==1
B=zeros(maxgen,1);
end

B(j)=max(sum(population(:,1)));
%disp(max(sum(population(:,1)))
); end toc; disp(population(:,1));
bar(B); grid on;

title('Static RWA Implementation with
GA'); xlabel('No. of Generations');
ylabel('No. of wavelengths used');
```

RESULT:

Elapsed time is 0.274220 seconds.

0	1	0	0	1	1	0	0
0	1	1	0	0	0	0	0
0	0	0	1	0	0	0	1
0	0	0	0	0	1	1	0
1	0	1	0	0	0	0	0
0	0	0	0	0	0	1	0
0	0	0	0	1	0	1	0
1	0	1	0	1	0	0	0

10 .Summary

The result shows that the GA is suitable in obtaining a near optimal solution in polynomial time. The performance of the Genetic Algorithm is compared under different fitness functions. A rigorous simulation decipher that the fitness function handling with minimizing the difference between the most congested link and average congestion between links in the network, produces near optimal results for most of the light path requests. The rest of the two fitness functions dealing with minimizing the congestion of the most congested link and minimizing the difference between most and least congested link in the network respectively, maintains a trade while optimizing various network parameters.

11 . Bibliography

- [1] Ahn, C. W. and Ramakrishna, R. S., "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.
- [2] Al-Fuqaha, A., Chaudhry, G. M., Guizani, M., and Labrador, M. A., "Routing Framework for All-Optical DWDM Metro and Long-Haul Transport Networks with Sparse Wavelength Conversion Capabilities," *IEEE Journal on Selected Areas in Communications*, vol. 22, pp. 1443–1459, 2004.
- [3] Ali, M., Ramamurthy, B., and Deogun, J., "Genetic Algorithm for Routing in WDM Optical Networks with Power Considerations Part I: The Unicast Case," in *Proceedings of the 8th IEEE ICCCN99*, (Boston-Natick, MA, USA), pp. 335– 340, 1999.
- [4] Banerjee, D. and Mukherjee, B., "A Practical Approach for Routing and Wavelength Assignment in Large Wavelength-Routed Optical Networks," *IEEE Journal on Selected Areas in Communications*, vol. 14, pp. 903–908, June 1996.
- [5] Banerjee, D. and Mukherjee, B., "Wavelength Routed Optical Networks: Linear Formulation Resource Budgeting Tradeo and A Reconfiguration Study," *IEEE/ACM Transactions on Networking*, vol. 8, pp. 598–607, October 2000.
- [6] Banerjee, N. and Kumar, R., "Multi Objective Network Design for Realistic Traffic Models," in *Proceedings of the Ninth Annual Conference on Genetic and Evolutionary Computation*, pp. 1904–1911, 2007.
- [7] Banerjee, N., Mehta, V., and Pandey, S., "A Genetic Algorithm Approach for Solving The Routing and Wavelength Assignment Problem in WDM Networks,"

21

44

in *Proceedings of International Conference on Networks*, (French Caribbean), pp. 70–78, 2004.

- [8] Banerjee, N. and Sharan, S., “A Evolutionary Algorithm for Solving the Single Objective Static Routing and Wavelength Assignment Problem in WDM Networks,” in *Proceedings of International Conference on Intelligent Sensing and Informa-tion Processing*, pp. 13–18, 2004.
- [9] Banerjee, S., Yoo, J., and Chen, C., “Design of Wavelength Routed Optical Networks for Packet Switched Tra c,” *IEEE Journal of Lightwave Technology*, vol. 15, pp. 1636–1646, September 1997.
- [10] Baroni, S., Bayvel, P., and Gibbens, R. J., “On The Number of Wavelengths in Arbitrarily-Connected Wavelength-Routed Optical Networks,” *Optical Society of America, TOPS*, vol. 20, pp. 195–204, 1998.
- [11] Basu, S. K., *Design Methods and Analysis of Algorithms*. Prentice-Hall of India Private Limited, 2005. ISBN-81-203-2637-7.
- [12] Bisbal, D., Miguel, I. D., Gonzalez, F., Blas, J., Aguado, J. C., Fernandez, P., Duran, J., and Lopez, M., “Dynamic Routing and Wavelength Assignment in Optical Networks by Means of Genetics Algorithms,” *Photonic Networks Communications*, vol. 7, no. 1, pp. 43–58, 2004.
- [13] Caenegem, B. V., Parys, W. V., Turck, F. D., and Demeester, P. M., “Dimensioning of Survivable WDM Networks,” *IEEE Journal on Selected Areas of Communications*, vol. 16, pp. 1146–1157, September 1998.

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

22

[15] Chlamtac, I., Ganz, A., and Karmi, G., "Lightnets: Topologies for Highspeed Optical Networks," *IEEE Journal of Lightwave Technology*, vol. 11, pp. 951–961, June 1993.