Wavelength Assignment in WDM Networks

Ninad Naval[1], Vinita Tiwari[2]

[1,2]Department of Electrical & Electronics, Birla Institute of Technology & Science, Pilani, India

Abstract: Advent of WDM has enabled us to use the optical fibres to its full capacity by multiplexing different signals into the same fibre. In an established network there is a need to optimize the use of number of wavelengths to minimize the use of network resources. Once the lightpaths are established the wavelength assignment problem mainly can be solved as graph coloring problem. Graph coloring algorithms are analyzed and compared with respect to number of colours used and the computation time.

Keywords: Graph Coloring, Wavelength Division Multiplexing, Chromatic Number, Routing and Wavelength Assignment, Lightpath

I. INTRODUCTION

This Optical fibres form the backbone of internet owing to its superior performance especially with respect to bandwidth and attenuation. To utilise the full capacity of the optical fibres WDM is used so that multiple signals travel through the same fibre at different wavelengths [1]. An end to end connection between two nodes connected through optical networks requiring no intermediate connection is referred to as lightpath [2]. There are two types of traffic demands – i) Static routing – where the connections between source and destination are fixed ii) Dynamic routing – where the demand of connection between source and destination varies with time.

For our analysis we concentrate only on static routing & assume that no wavelength converter is present at each node therefore request from one node to the other is to follow same wavelength even if it passes through intermediate node. For optimization in static case one have to deal with minimizing the no. of connections given the fixed no of wavelength or vice verse whereas in dynamic case requires minimizing the blocking probability [3]. In most of the cases routing and wavelength assignment problem can be treated as two sub-problems which are independent of each other [14].

Routing of the network can be done using any of the commonly known algorithms like Dijkstra's, Bellman-ford or LCP algorithm [5, 15] then wavelength assignment can be done using graph coloring algorithms.

Wavelength assignment problem deals with two constrains a) Wavelength Continuity constrain - particular request for a source-destination pair must follow a single lightpath b) Wavelength Conflict constrain – two signals can't use the same wavelength in the same fibre [4].

Wavelength assignment algorithm can be solved as graph coloring problem with above two constraints being incorporated as coloring rule. In graph coloring problem one has to color different nodes of the graph such that no two adjacent nodes in the graph are assigned the same color [16]. Given a routed networks with its lightpaths established one can easily generate graphs to solve wavelength assignment problem by representing each feasible connection by a node and connecting the nodes which share edges in the networks. More the number of nodes more it is difficult to optimise the number of colors as graph coloring is NP ((Non-deterministic Polynomial-time) hard problem. Different combinatorial and heuristic algorithms have been proposed in literature [6] to fulfil the graph coloring problem. In this paper we will analyze Greedy algorithm, Tabu search, Simulated annealing and Genetic algorithm.

II. ALGORITHMS USED FOR GRAPH COLORING

A. Greedy Algorithm

Greedy algorithm is easy to implement algorithm that looks for immediate solutions rather than the whole problem. Once the decision is taken it is not reconsidered. Greedy algorithms mostly provide satisfactory solutions and are fast to implement than most of the other available heuristic. Application of greedy algorithm for graph coloring is implemented as follows:

- Arrange the nodes in the graph in their decreasing order of degree i.e. number of nodes they are connected with.
- Start with the first node (largest degree) and assign first color (say, 1) to it.
- For all the remaining nodes in order of their degree assign the smallest color available so that it doesn't violate the coloring constrain.
- Stop when all the nodes are colored.

B. Simulated Annealing

Simulated annealing is a probabilistic method used to find global optimal solution. The idea is to reciprocate the cooling process of a solid material. The cooling process stops when the structure has acquired its minimum energy and hence stable structure. The analogy of reducing temperature is equivalent to reducing probability of accepting the worse solution in the solution space with each iteration [7]. The objective function represents the energy of the system and the control variable T represents its temperature. The steps involved in solving graph coloring problem with simulated annealing process are as follows [8]:

- Given a graph G, maximum number of iterations N, decreasing factor α, acceptance probability P, minimum number of colors kmin and initial temperature T0.
- Assign unique color to each node in the graph G.
- Define energy E as number of colors used to color the graph.
- While T>0 or E>kmin
- Select a random node and assign a random color to it making sure that it does not violate the coloring constrain.
- Accept the change if the change in energy is negative or if exp $(-\delta E/T) > P$.
- $T = \alpha T$

C. Genetic Algorithm

Genetic Algorithm attempts to simulate the natural selection process which favours the fittest individuals. Operations such as crossover and mutation are simulated to obtain the desired solution. The fitness of the individual solution is defined by the nature of problem involved. In case of graph coloring problem it is defined as the number of bad edges. The less the number of bad edges the fitter the individual. An individual in the population for N node graph is defined as 1xN matrix where each term represents the color assigned to the node. For example (1 3 4 5) represents color 1 assigned to node 1, color 3 to node 2 and so on. A crossover is defined as exchange of terms at certain point between two individuals to generate a child [4]. Steps involved in implementing genetic algorithm for graph coloring are summarized below [9, 10]:

- Given a graph G, maximum number of generations Ng, population size N, minimum number of colors kmin [11].
- Generate random population of size N with each chromosome having color from 1 to kmin.
- Define fitness function F as number of bad edges i.e. number of violation in the coloring scheme.

- While n<Ng or F=0

    a) For each new generation remove the bottom half of the population (half with poorer fitness)

    b) If best fitness > 4

        Repeat N/2 times

        i) Select two parents by contesting random individual against each other and selecting the best among them.

        ii) Apply single point crossover at a point from where first unfeasible color appears to the parents generated in the previous step to generate a new child and add to the population.

        iii) Apply mutation with probability 0.8 to the generated child and assign appropriate color to the node violating the coloring constrain.

    c) If best fitness < 4

        Repeat N/2 times

        i) Select the best individual from the remaining half and add it to the population.

        ii) Apply mutation to the generated child with probability 0.8 by assigning random color to the nodes which are violating the coloring constrains.

- n=n+1

D. Tabu Search

Tabu search is local search method but it differs from it in a way that certain points in the solution are not allowed. A point leading backward or to a poorer solution is not allowed. For that purpose a tabulist is maintained and points existing in the list are not allowed. This allows the method to find global optimum instead of local optimum [12]. The points remain in the list for certain specified amount of time. Given number of colors the algorithm attempts to find feasible coloring rather than optimized solution. The steps involved are as follows [13]:

- Given a graph G, minimum number of colors kmin, length of tabulist N, maximum number of iterations nmax.
- Define fitness function, F, as number of violation in the coloring scheme.
- Randomly generate a coloring scheme by choosing colors between 1 to kmin.
- While n<nmax or F>0

a) Select a random node violating the constrain and assign appropriate color to it.

b)   If the new coloring scheme exist in the tabulist repeat step a)

- Update the tabulist by adding the new coloring scheme at the top of it and removing the last entry from the tabulist.

III. DATA

The instances used in testing the algorithms are derived from DIMACS benchmarking graph collection. DIMACS is the Centre for Discrete Mathematics and Theoretical Computer Science. Certain instances such as *myciel3, myciel4 and myciel5* are graphs based on the Mycielski transformation. These graphs are difficult to solve because they are triangle free but the coloring number increases in problem size. The other instances, queen5_5 and queen6_6 are queen graph on n^2 nodes, each corresponding to a square of the board. Finally *david* and *anna* are the instances derived from the literature work David Copperfield and Anna Karenina respectively where each node represents a character and edges represents their encounter with each other.

IV. RESULTS

The above instances were run on 2.3 GHz workstation in Matlab platform. The results are summarized in Table I and Table II. Figure 1 show number of colors used by the algorithms to color the graph vs. number of nodes in the graph.

Table I.
Table listing number of colors used by various algorithms

File	Nodes	Edges	Chromatic Number	Greedy Algorithm	Tabu search	Simulated annealing	Genetic Algorithm
Myciel3	11	20	4	4	4	4	4
Myciel4	71	23	5	5	5	5	5
Myciel5	47	236	6	6	6	6	6
Queen5_5	25	160	5	7	7	5	5
Queen6_6	36	290	7	9	10	8	8
David	87	406	11	11	12	13	11
Anna	138	493	11	11	15	17	11

Table II.
Table listing time taken to implement instances on various algorithms

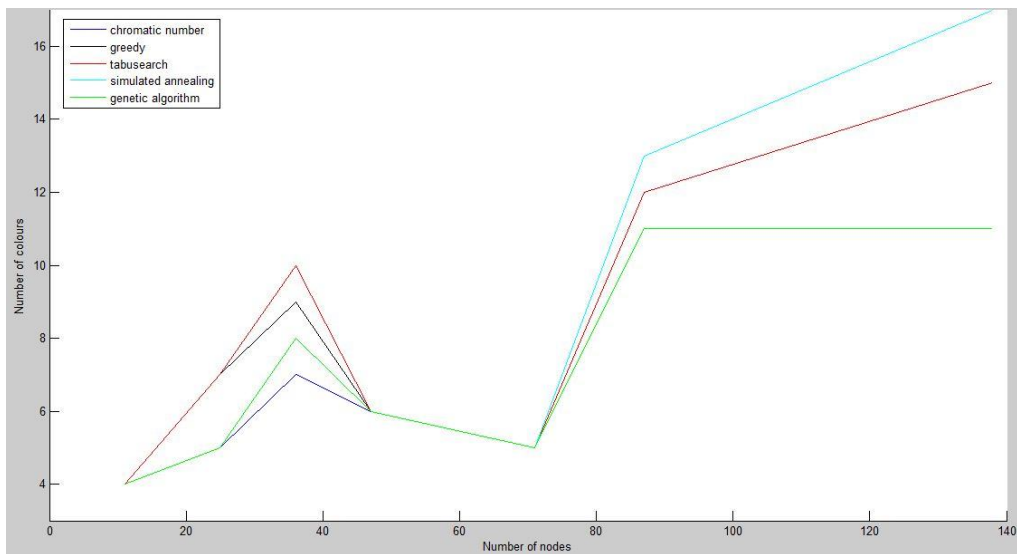| File	Nodes	Edges	Greedy Algorithm (in sec)	Tabu search (in sec)	Simulated annealing (in sec)	Genetic Algorithm (in sec)
Myciel3	11	20	0.052	0.09	0.43	0.112
Myciel4	71	23	0.052	0.284	0.52	0.285
Myciel5	47	236	0.063	12.65	44.24	0.462
Queen5_5	25	160	0.057	5.2	2.38	1.05
Queen6_6	36	290	0.068	43.259	15.31	206.91
David	87	406	0.119	153.65	37.62	0.627
Anna	138	493	0.151	162.35	305.12	1.02

Fig. 1 Graph showing number of colors vs. number of nodes for different algorithms

V. CONCLUSION

In this paper algorithms for solving graph coloring problem and hence wavelength assignment in optical networks were implemented on certain instances of varying node sizes. The comparison was done on the basis of number of colors used to color the instance and time taken by each algorithm for the same. It can be observed that with the increase in the number of nodes the solution time as well as number of colors increases rapidly for tabusearch as well as simulated annealing. On the other hand greedy algorithm was successful in faster implementation of the algorithms though resulting in more than chromatic number in few cases. The most accurate of the four algorithms is genetic algorithm which used optimum number of colors in most of the cases but was more time consuming in certain cases. Based on above observations it can be concluded that greedy algorithms must be used in case where fast results are required and low accuracy can be tolerated and genetic algorithms must be used for optimum usage of network resources.

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