A Genetic Algorithm Way of Solving RWA Problem in All Optical WDM Networks

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Abstract. This research work presents a Genetic Algorithm (GA) heuristic approach to solve the static Routing and Wavelength Assignment (RWA) problem in Wavelength Division Multiplexing (WDM) networks under wavelength continuity constraint. The RWA problem is modeled as an Integer Linear Programming (ILP) problem with the optimization objective to balance the network load among the connection requests. We consider ARPANET as the standard simulation network and use Genetic Algorithm technique to solve the formulated ILP on such network to produce a near optimal solution in polynomial time. We state three different fitness functions, all of them aim at balancing the network load among individuals and compare them while optimizing different network parameters.

Keywords: Genetic Algorithm; RWA problem; WDM network; wavelength continuity constraint; Integer Linear Programming; fitness function.

1 Introduction

Routing and Wavelength Assignment (RWA) [1] is a well known issue in Wavelength Division Multiplexing (WDM) optical networks [2]. In such networks, each fiber link is logically divided into multiple number of non interfering wavelength channels. The RWA problem assumes determining the routes and wavelengths to be used to create the lightpaths [1] for the connection requests.The RWA problem can be separated into two sub-problems, routing allocation and wavelength channel assignment. The first subproblem determines the physical links that will define each lightpath while the second subproblem assigns wavelength(s) to each lightpath. The RWA problem has been previously considered for various design objectives, for instance, minimizing the number of wavelengths required on each edge while satisfying all connection requests in the demand matrix or maximizing the number of accepted connection requests given a limited number of wavelength channels per fiber link. The optimal solution to the RWA problem is found to be NP-hard [3] and thus suited to heuristic methods [4–6].

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2 Proposed Work

We consider the static version of the RWA problem and optimize different RWA objective criteria enumerated as follows:

- minimizing the congestion of the most congested link in the network
- minimizing the difference between most congested and least congested link
- minimizing the difference between most congested link and average congestion of all links in the network.

The Min-RWA problem is modeled as an Integer Linear Programming (ILP) problem with suitable constraints to establish loop free resilient lightpaths. The formulated ILP tailored with Genetic Algorithm (GA) heuristic is implemented on ARPANET (Advanced Research Project Agency NETwork) to produce a near optimal solution.

3 Statement of the Problem Formulation

We assume a network that maintains wavelength continuity constraint. The given optical network is supposed to be single fiber. The optical network is viewed as a graph $G = (V, E)$ where V is the set of nodes and E is the set of undirected edges. Let W be the set of wavelengths supported by every fiber link in the network and K be the set of static lightpath requests.The demand matrix is specified by D where D_{ij} defines the maximum demand between node pair i and j. The variables of concern of the formulated ILP are defined as follows:

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

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

The network design formulations stated here is to optimize three different objective functions:

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

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

$$Minimize \quad \max_{e \in E} \sum_{k \in K} \sum_{w \in W} x_k^{w,e} - \frac{\sum_{k \in K} \sum_{e \in E} \sum_{w \in W} x_k^{w,e}}{|E|} \tag{3}$$

subject to:

– Wavelength continuity constraint:

$$\sum_{w \in W} x_k^w \leq 1; \forall k \in K \tag{4}$$

– Wavelength distinct constraint:

$$\sum_{k \in K} x_k^{w,e} \leq 1; \forall w \in W and \forall e \in E \tag{5}$$

– Demand constraint:

$$|\{k \in K| \sum_{e \in \omega^-(i)} \sum_{w \in W} x_k^{w,e} - \sum_{e \in \omega^+(i)} \sum_{w \in W} x_k^{w,e} = -1$$
$$\wedge \sum_{e \in \omega^+(j)} \sum_{w \in W} x_k^{w,e} - \sum_{e \in \omega^-(j)} \sum_{w \in W} x_k^{w,e} = -1\}| \leq D_{ij} \tag{6}$$

– Wavelength reservation constraint:

$$\sum_{e \in \omega^-(v): v \in V - \{s_k, d_k\}} x_k^{w,e} - \sum_{e \in \omega^+(v): v \in V - \{s_k, d_k\}} x_k^{w,e} = 0; \forall k \in K and \forall w \in W \tag{7}$$

– No looping constraint around source node(s_k):

$$\sum_{e \in \omega^-(s_k): s_k \in V} \sum_{w \in W} x_k^{w,e} = 0; \forall k \in K \tag{8}$$

– No looping constraint around destination node(d_k):

$$\sum_{e \in \omega^+(d_k): d_k \in V} \sum_{w \in W} x_k^{w,e} = 0; \forall k \in K \tag{9}$$

– No looping constraint around intermediate nodes:

$$\sum_{e \in \omega^-(v): v \in V - \{s_k, d_k\}} \sum_{w \in W} x_k^{w,e} \leq 1; \forall k \in K \tag{10}$$

$$\sum_{e \in \omega^+(v): v \in V - \{s_k, d_k\}} \sum_{w \in W} x_k^{w,e} \leq 1; \forall k \in K \tag{11}$$

$$\sum_{e \in \omega^+(v): v \in V - \{s_k, d_k\}} \sum_{w \in W} x_k^{w,e} - \sum_{e \in \omega^-(v): v \in V - \{s_k, d_k\}} \sum_{w \in W} x_k^{w,e} = 0; \forall k \in K \tag{12}$$

– Hop-Count Constraint:

$$\sum_{e \in E} \sum_{w \in W} x_k^{w,e} \leq H \quad where \quad H = \max_{(s_k, d_k)} \{d(s_k, d_k)\} + \alpha \tag{13}$$

where $d(s_k, d_k)$ is the minimum distance between a node pair (s_k, d_k) and the parameter α depends on the routing heuristic.

4 The GA Approach to Solve the RWA Problem

4.1 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 $\left(n_{i0} \; ... \; n_{ih(i)}\right); n_{i0}, ...n_{ih(i)} \in V$.

4.2 Initial Population

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 of the first iteration. 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. In this work, a population size of 50 is maintained.

4.3 Fitness Function

We state three different fitness functions corresponding to different RWA objective criteria as stated in Eq. 1, Eq. 2 and Eq. 3.

$$\begin{aligned} y_1 &= 1 - \tfrac{max\_con}{|K|} \\ y_2 &= 1 - \tfrac{max\_con - min\_con}{|K|} \\ y_3 &= 1 - \tfrac{max\_con - avg\_con}{|K|} \end{aligned} \tag{14}$$

where
max_con= congestion of the most congested link in the network
min_con=congestion of the least congested link in the network
avg_con=average congestion of all links in the network
$|K|$=number of static lightpaths

4.4 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 [7].

4.5 Crossover

In the selected generation, with a certain crossover probability 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. In the simulation work, the crossover rate is maintained at 0.5 and the crossover ratio is limited to 0.2.

Table 1. Demand set of static lightpath requests

Lightpath(s_i, d_i)	Minimum cost path(p_i)
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

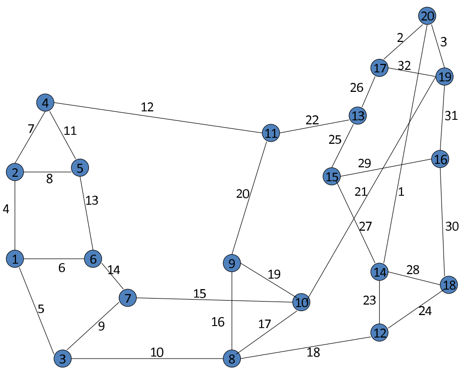

Fig. 1. Advanced Research Project Agency Network

4.6 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 $l > j + 1$. Calculate the minimum cost path between n_{ij} and $n_{i(j+1)}$; replace the corresponding portion in p_i using the new path. In the simulation work, the mutation rate is maintained at 0.1 and the mutation ratio is limited to 0.2.

5 Simulation Result

The formulated ILP tailored with GA is simulated on ARPANET (see Fig. 1) to satisfy a set of static lightpath requests which is listed in Tab. 1. The stopping criterion for the GA is the maximum number of generations which is restricted to 100 in this simulation work. The performance comparison among the RWA objectives is based on their ability to optimize various network parameters and is shown in Tab. 2.

Table 2. Performance comparison among RWA objective criteria

Type of fitness functions	comparison
fitness function: y_1	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: 505 The maximum hops traversed by a lightpath: 07 The number of fibers used to honor all the lightpaths: 24 The maximum delay of a lightpath: 100
fitness function: y_2	The maximum fitness of a chromosome after required number of generations is: 0.9 The network load for establishing 10 lightpaths is: 02 The total delay in establishing all the lightpaths is: 433 The maximum hops traversed by a lightpath: 06 The number of fibers used to honor all the lightpaths: 22 The maximum delay of a lightpath: 68
fitness function: y_3	The maximum fitness of a chromosome after required number of generations is: 0.956 The network load for establishing 10 lightpaths is: 02 The total delay in establishing all the lightpaths is: 793 The maximum hops traversed by a lightpath: 10 The number of fibers used to honor all the lightpaths: 29 The maximum delay of a lightpath: 178

6 Conclusion and Future Work

Among the stated RWA objectives, the objective of minimizing the difference between most congested and least congested link in the network provides best performance while optimizing different network parameters such as congestion, delay, maximum hop count and total number of fibers used to honor all the lightpaths. The simulation work may be extended further to accommodate different sets of lightpath requests and the ability of the RWA objectives can be compared as they optimize various network parameters while establishing these sets of lightpath requests; thereby analyzing any alteration in their performances.

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