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A self-adaptive multi-objective genetic algorithm for the QoS based routing and wavelength allocation problem in WDM network

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ABSTRACT

To tackle the QoS based routing and wavelength allocation problem, a self-adaptive multi-objective genetic algorithm based on decomposition is presented. The chromosome coding scheme, crossover and mutation operators are redefined, and a repair method is proposed to guarantee the generated offspring are valid. The proposed algorithm was evaluated on a set of different scale test problems and compared with the recently proposed related algorithms. The experimental results revealed encouraging results in terms of the solution quality and the processing time.

1. Introduction

In WDM network, the routing and wavelength assignment (RWA) is a well-known NP-completer problem [9]. But, with the development of network transmission business, many emerging network services require specialized Quality of Service (QoS). The provisioning of QoS based network routing and wavelength assignment is becoming more and more demanding, which is in general terms a more complex problem [17]. Since the QoS is multidimensional concept and usually more than one QoS related objectives and constraints will be considered during setting up light-path by routing and assigning a wavelength to each connection, the QoS based routing and wavelength allocation problem (QRWA) is an intrinsically multi-objective optimization problem.

Due to the computational complexity, the most related researches are concentrated on heuristic-based algorithms [1,11,13] especially the meta-heuristic approaches [4,7,9,10,15] aiming to find near-optimal solutions. Furthermore, the most existing methods divide this problem into two separate single objective sub-problems and include two consecutive optimization phases, one phase for the routing process, and the other for the wavelength allocation process. Several multi-objective optimizing methods are not applied for this problem until recently, which tackle multiple objectives simultaneously. In [18], the SPEA algorithm [5] is applied to solve the QRWA problem. In [9], a hybrid evolutionary computation approach consisting of genetic algorithm for routing allocation with minimum degree first for wavelength assignment (GA-MDF) and the fast non-dominated sorting genetic algorithm to search for non-dominated solutions is applied for solving the multi-objective RWA network design problem. In [4], a multi-objective genetic algorithm (MOGA) that uses classical multi-objective optimization strategies to jointly solve the static impairment aware RWA (IA-RWA) problem. We can see that the most existing researches take the RWA as a single objective optimization problem, and few researches has been done for the multi-objective QRAW problem.

As a novel meta-heuristic approach, the GA algorithm was proposed in the 1970s by John Holland at University of Michigan, motivated by the process of natural evolution. It has been extensively studied and successfully applied to solve many multi-objective optimization problems [2,3,5,12,14,16]. In this paper, a novel self-adaptive multi-objective genetic algorithm called QRWA_DMGA is proposed to tackle the multi-objective QRWA problem, which is based on the ideas of self-adaptive decomposing a multi-objective optimization problem into a number of scalar optimization sub-problems and optimizing them simultaneously. In this algorithm, a variable-length node chromosome encoding scheme is defined and used to represent the candidates, and the crossover and mutation schemes are redefined to adapt to this problem. In order to efficiently construct a valid candidate, a repair process based on depth first search approach is proposed. To show the effectiveness of this algorithm, it is evaluated on a set of different scale test problems and compared with the recently related GA based multi-objective optimization algorithms. This paper is organized as follows. In Section 2, we give the model definition of QRWA problem, including the considered QoS indicators and their definitions. The detail of the QRWA_DMGA algorithm is provided in Section 3. The experiments and comparative studies are given

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in Section 4. Finally, Section 5 summarizes the contribution of this paper along with some future research directions.

2. The definition of the QRWA problem

For a given WDM network, it can be modeled as a weighted undirected graph $G=(V,E)$, where N is the set of nodes and E is the set of edges. There are two weight vectors W and Q containing the information of wavelengths and QoS attributes respectively corresponding to each edge in E. Then the QRWA problem in this paper is to find the best light-paths from the source node $v_s \in N$ to the destination node $v_d \in N$ that meets different optimization criteria and satisfies the specified constraints. In the considered communication model, a light-path $P_{s,d}$ is composed of a path from source node v_s to the destination node v_d denoted as a node sequence $V=\{v_s, v_i, v_j, \ldots, v_k, v_t, v_d\}$, and a set of allocated wavelengths of this path $W_\lambda=\{\lambda_{s,i}, \lambda_{i,j}, \ldots, \lambda_{k,t}, \lambda_{t,d}\}$, where λ_{ij} represents the allocated wavelength for the edge $(v_i, v_j) \in E$. We use the $P_{s,d}=(V, W_\lambda)$ to represent a light-path with source-destination node pair (s,d), and use the vector $Q_p=\{f_1(p), f_2(p), \ldots, f_r(p)\}$ to represent the global QoS values of light-path p, and the function $f_i(p)$ determines the published value of the ith attribute of the light-path p. In this paper, the attribute cost, delay and wavelength are considered. Based on the above description, the considered QRAM problem model can be formulated as follows:

$$\text{Min}: \quad f(p) = (f_1(p), f_2(p)) \tag{1}$$

where

$$f_1(p) = \sum_{\lambda \in W} \sum_{(i,j) \in E} c_{ij} x_{ij}^{\lambda} \quad \text{(Cost function)} \tag{2}$$

$$f_2(p) = 1 - \frac{\sum_{\lambda \in W} \sum_{(i,j) \in E} (r_{ij}^{w}/b_{ij}^{\lambda}) x_{ij}^{\lambda}}{\sum_{\lambda \in W} \sum_{(i,j) \in E} x_{ij}^{\lambda}}$$

$$\text{(Wavelength utilization function)} \tag{3}$$

Subject to the following constraints:

$$\sum_{(i,j) \in E} X_{ij}^{\lambda} = 1, \quad \forall \lambda \in W, \quad i = s \tag{4}$$

$$\sum_{(i,j) \in E} X_{ij}^{\lambda} = 1, \quad \forall \lambda \in W, \quad j = d \tag{5}$$

$$\sum_{(i,j) \in E} X_{ij}^{\lambda} - \sum_{(j,i) \in E} X_{ji}^{\lambda} = 0, \quad \forall \lambda \in W, \quad i \neq s, \quad j \neq d \tag{6}$$

$$r_{ij}^{w} \le c_{ij}^{\lambda}, \quad \forall (i,j) \in E \tag{7}$$

$$\sum_{\lambda \in W} \sum_{(i,j) \in E} d_{ij} . x_{ij}^{\lambda} < L \tag{8}$$

The L is a constant, indicating the user delay requirement. The c_{ij} and d_{ij} denote the cost and delay time of the edge (v_i, v_j) respectively. The x_{ij}^{λ} is a binary variable. It takes the value of 1, if the wavelength λ of edge (v_i, v_j) is used to transport the data stream; otherwise, it takes the value of 0. The r_{ij}^{w} is the demand of data flow and the b_{ij}^{λ} is the capacity of the wavelength λ of the edge (v_i, v_j).

3. The solving algorithm

The idea of decomposition has been used to a certain extent in several meta-heuristics for multi-objective optimization problems (MOP) [12]. In this paper, we combined the idea of decomposition with the genetic algorithm and proposed the QRWA_DMGA algorithm for the QRWA problem. It self-adaptively decomposes the QRWA into a number of scalar optimization sub-problems and solves these sub-problems simultaneously by evolving a population of solutions. At each generation, the population is composed of the best solution found so far for each sub-problem. If the best solution of a sub-problem has not been updated during T generations, a new sub-problem will be generated based on its neighbors to replace it. The neighborhood relations among these sub-problems are defined based on the distances between their aggregation coefficient vectors and each sub-problem is optimized by using information only from its neighboring sub-problems. In order to preserve the obtained non-dominated solutions, an external archive is used QRWA_DMGA algorithm. The Dominance concept [8] used is defined as follows:

Definition (*Dominance*). For the two feasible solutions X and Y of a minimization optimization problem: $min\, F=(f_1, f_2, f_3, \ldots, f_k)$, say X dominate Y $(X \angle Y)$, *iff* $\forall i, f_i(X) \le f_i(Y)$, and $\exists i, f_i(X) < f_i(Y)$, $i \in [1,k]$.

Furthermore, in order to apply the genetic algorithms to solve the QRWA problem, the problems of chromosome coding and definitions of the using operators must be solved. In this paper, the chromosome is defined as nodes sequence $(s, v_1, v_2, \ldots, v_i, \ldots, v_n, d)$ with the correlative wavelengths sequence $(\lambda_{s,v_1}, \lambda_{v_1,v_2} \ldots, \lambda_{v_i,v_j}, \ldots, \lambda_{v_n,d})$ between source-destination node pair (s,d). The chromosome is represented as Fig. 1.

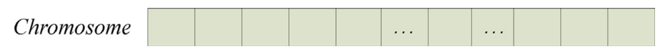

Fig. 1. The chromosome encoding scheme.

Based on this representation of chromosome, a repair process is designed and used to ensure the generated offspring being a connected light-path, which is detailed as follows:

```
procedure repair()
Input
  Chromosome C;  //the chromosome need to be repaired
Node n_s;  //the start node for repair, n_s ∈ C
  NodeSet D;  //it contains the optional valid end nodes
Output
  Chromosome C';  //the repaired Chromosome.
Begin
  V = ∅;  //V is a NodeSet storing the visited nodes
  int i = 0;
  do{
    C' [i] = C [i];
    i = i + 1;
    if (i mod 2 ≠ 0) then add C [i] into V;
  }while (C[i] ≠ n_s);
  do{
    if (∃k, n_k ∈ N_i ∧ n_k ∉ V) then//N_i: neighbor of the node C[i];
    {
    add n_k into V;
    //allocate an available wavelength
    if (∃λ,(λ ∈ W[C' [i], n_k]) ∧ (λ is usable)) then {C' [i + 1] = λ; C' [i + 2] = n_k}
  else break;
    if (n_k ∈ D ∧ n_k ≠ d) then
    {
      do
        i = i + 1;
        C' [i] = C[i];
      while (C' [i] ≠ d);
    }
    return;
    }else i = i − 2;
  } while (n_k ∈ D);
End.
```

We can see that this process is based on the depth-first searching algorithm (DFS). When any node contained in set D is visited, the process is stopped, which means a valid light-path has been found. This process can also be used to initialize a chromosome, when set the n_s as node s and d as the only element contained in