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Hybrid evolutionary algorithms for the Multiobjective Traveling Salesman Problem

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ABSTRACT

In the Multiobjective Traveling Salesman Problem (moTSP) simultaneous optimization of more than one objective functions is required. In this paper, three hybrid evolutionary algorithms with common characteristics are proposed and analyzed for the solution of the Multiobjective Traveling Salesman Problem. The two hybrid evolutionary algorithms are based on Differential Evolution algorithm and the third one is a hybridized version of the NSGA II. One of the challenges of the proposed algorithms is the efficient application of an algorithm, the Differential Evolution algorithm, which is suitable for continuous optimization problems, in a combinatorial optimization problem. Thus, we test two different versions of the algorithm, the one with the use of an external archive (denoted as MODE) and the other using the crowding distance (denoted as NSDE). Also, another novelty of the proposed algorithms is the use of three different mutation operators in each of the two versions of the Differential Evolution algorithm leading to six different algorithms (MODE1, MODE2 and MODE3 for the first version and NSDE1, NSDE2 and NSDE3 for the second version). We use in each algorithm a Variable Neighborhood Search (VNS) procedure in each solution separately in order to increase the exploitation abilities of the algorithms. In order to give the quality of the algorithms, experiments are conducted using classic Euclidean Traveling Salesman Problem benchmark instances taken from the TSP library. Also, we use a number of different evaluation measures in order to conclude which of the three algorithms is the most suitable for the solution of the selected problem. In general, the proposed algorithms can easily be applied in all multiobjective routing problems by changing the objective function and the constraints of the problem and they have the ability to use more than two objective functions (in the paper we test the algorithm with up to five different objective functions). The hybridized use of the global search algorithm, the Differential Evolution, with the Variable Neighborhood Search increases the exploration and the exploitation abilities of the algorithms giving very effective evolutionary multiobjective optimization algorithms.

1. Introduction

In real world applications, optimization problems with more than one objectives are very common. Thus, in these problems (Multiobjective Optimization Problems), usually, there is no single solution. The solution of Multiobjective Optimization problems with the use of evolutionary algorithms is a field that has been extensively studied during the last years. For a complete survey of the field of the evolutionary multiobjective optimization please see Abraham, Jain, and Goldberg (2005) and Coello Coello, Van Veldhuizen, and Lamont (2007).

The *Traveling Salesman Problem* (*TSP*) is the problem of finding the shortest tour through all the cities that a salesman has to visit. The TSP is probably the most famous and extensively studied problem in the field of Combinatorial Optimization (Gutin & Punnen, 2002; Lawer, Lenstra, Rinnoy Kan, & Shmoys, 1985). The TSP belongs to the class of NP-hard optimization problems (Johnson & Papadimitriou, 1985). A number of variants of the classic Traveling Salesman Problem have been proposed like the traveling salesman with time windows, multi-traveling salesman problem, the probabilistic traveling salesman problem, the prize collecting traveling salesman problem, etc. The *Multiobjective Traveling Salesman Problem (moTSP)* is the variant of the classic traveling salesman problem where simultaneous optimization of distances, costs, times, or other relevant objectives are required (Samanlioglu, Ferrell, & Kurz, 2008). In this research, the symmetric case is considered where the distance, time, or cost between cities are known and symmetric. In practical moTSP applications, there might be several competitive objective functions such as cost factors related to distance, expenses, travel time, degree of risk, energy consumption, and other relevant considerations for the tour (Samanlioglu et al., 2008).

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The Multiobjective Traveling Salesman Problem is an NP-hard problem. The instances with a large number of customers cannot be solved in optimality within reasonable time. For this reason a large number of approximation techniques have been proposed for its solution. These techniques are classified into three main categories: the classical heuristics, the single solution based metaheuristics and the population based metaheuristics. More precisely, algorithms based on two phase local search (Paquete & Stutzle, 2003), two phase Pareto local search (Lust & Jaszkiewicz, 2010; Lust & Teghem, 2010a), stochastic local search (Paquete & Stutzle, 2009), tabu search (Hansen, 2000), genetic algorithms (Elaoud, 2010; Jaszkiewicz, 2002; Samanlioglu et al., 2008), evolutionary algorithms (Kumar & Singh, 2007), co-evolution strategies (Yang, Kang, & Kang, 2008), memetic algorithms (Jaszkiewicz & Zielniewicz, 2009) and ant colony optimization (Angus, 2007; Garcia-Martinez, Cordon, & Herrera, 2007) have been proposed in order to give efficient algorithms for the solution of the Multiobjective Traveling Salesman Problem. A complete survey about the Multiobjective Traveling Salesman Problem can be found in Lust and Teghem (2010b).

A number of publications for the solution of the multiobjective TSP and its variants have been studied in the last two years (2014–2015). The multiobjective TSP under stochastic environment was proposed by He, Wang, Pan, and Wang (2014). Changdar, Mahapatra, and Pal (2014) proposed a multiobjective genetic algorithm in order to solve a multiobjective solid TSP considering that the first objective is the cost and the second is the time. Both of them are fuzzy in nature. Li (2014) proposed to solve a 2-objectives and 3-objectives dynamic multiobjective TSP using a parallel search system. Florios and Mavrotas (2014) managed to produce the exact Pareto front for two objective functions using the AUGMECON2 method for the multiobjective TSP and for the multiobjective SCP (Set Covering Problem). Two variants of the multi-objective chemical reaction optimization (MOCRO) algorithm was used by Bouzoubia, Layeb, and Chikhi (2014) in order to produce solutions for the multiobjective TSP. This algorithm uses a non-dominated sorting procedure similar with the one used in the NSGA II algorithm. The solution of the multiobjective multiple traveling salesmen problem using membrane algorithms was proposed by He (2014). On the other hand, Bolanos, Echeverry, and Escobar (2015) solved the same problem using a NSGA II algorithm. Luo, Liu, Hao, and Liu (2014) proposed a new variant of the NSGA II algorithm (INSGA-II-MOTSP) for the solution of the multiobjective TSP. This algorithm used a layer strategy in order to avoid the production of unnecessary Pareto fronts. Another multiobjective TSP, the bi-objective multiple traveling salesman problem with profits (BOMTSPP) was proposed by Labadie, Melechovsky, and Prins (2014). In this problem there are two objectives. The minimization of the total route cost and the optimization of the profits that are collected from the costumers. The problem was solved using a Path Relinking algorithm and a NSGA II algorithm. Wang, Guo, Zheng, and Wang (2015b) proposed a new variant of the multiobjective TSP, the uncertain multiobjective TSP with uncertain variables on the arcs. The solutions in this problem were given by a combination of a variant of the Artificial Bee Colony (ABC) algorithm with an uncertain approach. A new hybrid NSGA II algorithm was proposed in (Wang, Sanin, & Szczerbicki, 2015a) for the solution of the multiobjective TSP. A review of the recently proposed ant colony optimization algorithms for Multiobjective Traveling Salesman Problems using two to four objective functions is given in Ariyasingha and Fernando (2015).

In this paper, three new multiobjective evolutionary algorithms are presented and compared between them. The two of them are based on Differential Evolution algorithm with new mutation operators and the third is a hybridized version of NSGA II. The main characteristics of the proposed multiobjective algorithms are the following.

(1) Usually the Multiobjective Differential Evolution algorithms are used to solve continuous optimization problems. The main contribution of this paper is the development of two multiobjective optimization algorithm based on the Differential Evolution (DE) principles which will be applied directly in combinatorial optimization problems, like the Multiobjective Traveling Salesman Problem.
(2) Three new equations for the mutation operator for each one of the Differential Evolution versions are used. We propose these equations as we would like to answer to the main issues raised in a Multiobjective Differential Evolution algorithm, namely, which individuals will be selected for the production of the trial vector, which individuals will play the role of the parents and how the solutions of the Pareto front will affect the trial vectors. These three equations combine solutions from the Pareto front and from the population with different ways in order to find the most efficient mutation operator for the selected problem.
(3) A hybridized version of NSGA II, suitable for combinatorial optimization problems, is presented.
(4) Two different versions of the proposed algorithm, one with the use of the crowding distance (just like in the hybrid NSGA II) and one without are presented.
(5) The combination of all algorithms with a very powerful metaheuristic algorithm, the Variable Neighborhood Search (VNS) (Hansen & Mladenovic, 2001), is performed.

In our research, three variants of a Nondominated Shorting Deferential Evolution algorithm are proposed and are compared with three variants of a Multiobjective Differential Evolution algorithm and a NSGA II algorithm. In the literature, there is no other research, at least to our knowledge, that combines the Differential Evolution algorithm with the NSGA II sorting principles in order to create a Nondominated Shorting Differential Evolution algorithm for the solution of the multiobjective TSP. Furthermore, in our research we propose three new variants of the equation that is used for the calculation of the trial vector that combine individuals from the Pareto front and, also, from the current population of individuals. Also, usually the initial population for an evolutionary algorithm is produced randomly. On the other hand, considering the work of Kumar and Singh (2007) the initial population is separated in as many sub-populations as the objective functions are. Then, for each sub-population a set of optimized solutions for each objective function is used for the initial population. In the main phase of the algorithm, those solutions are evolved and the non-dominated solutions are the Pareto front's solutions of each iteration. In the proposed algorithms, an advanced variant of the Kumar and Singh method is proposed. The solutions of each sub-population are produced by using four different local search methods in order to give more exploitation and exploration abilities in the initial population. Furthermore, the evolutionary algorithms are not suitable for combinatorial optimization. In our research, we use a method in order to transform each element of the solution (path representation of the tour) into a floating point in the interval (0,1] and vice versa by using a method that is proposed by Marinakis, Iordanidou, and Marinaki (2013) in order to create evolutionary algorithms suitable for combinatorial optimization problems. Also, all the proposed algorithms are hybrid and are combined with a proposed Variable Neighborhood Search algorithm in order to improve the solutions. This method is more effective than a simple local search method and gives more exploration abilities to the solutions. In comparison to recent researches (Ariyasingha & Fernando, 2015; Florios & Mavrotas, 2014) that use the kro instances for the solution of the MOTSP for the combination of two to four objective functions, in our work, the proposed algorithms give results for the multiobjective TSP that combine from two to five objective functions.

It is very important to mention the need for the development of a very efficient algorithm for this problem. Ideally, an Expert and Intelligent System will have to replace the decision maker (the human