Applied Soft Computing 26 (2015) 74–89

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

Two metaheuristic approaches for the multiple traveling salesperson problem

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A R T I C L E I N F O

Article history:
Received 2 October 2013
Received in revised form 4 August 2014
Accepted 18 September 2014
Available online 30 September 2014

Keywords:
Artificial bee colony algorithm
Constrained optimization
Invasive weed optimization algorithm
Multiple traveling salesperson problem
Swarm intelligence

A B S T R A C T

The multiple traveling salesperson problem (MTSP) is similar to famous traveling salesperson problem (TSP) except for the fact that there are more than one salesperson to visit the cities though each city must be visited exactly once by only one salesperson. For this problem, we have considered two different objectives. First one is to minimize the total distance traveled by all the salespersons, whereas the second one is to minimize the maximum distance traveled by anyone salesperson. This latter objective is about fairness as it tries to balance the workload among salespersons. MTSP, being a generalization of TSP under both the objectives, is also $\mathcal{NP}$-Hard. In this paper, we have proposed two metaheuristic approaches for the MTSP. The first approach is based on artificial bee colony algorithm, whereas the second approach is based on invasive weed optimization algorithm. We have also applied a local search to further improve the solution obtained through our approaches. Computational results on a wide range of benchmark instances show the superiority of our proposed approaches over all the other state-of-the-art approaches for this problem on both the objectives.

1. Introduction

The multiple traveling salesperson problem (MTSP) is an extension of famous traveling salesperson problem (TSP), where more than one salesperson are present to visit the cities though each city must be visited exactly once by only one salesperson. Given a set of n cities to be visited by a salesperson, the TSP seeks the shortest possible tour for the salesperson that visits each city exactly once and return to the starting city. However, in case of MTSP, there are m salespersons instead of one to visit $n > m$ cities and we have to find the tours for all m salespersons. The starting and ending cities are called depots, and the remaining cities are called intermediate cities. There are several versions of MTSP depending on the number of depots.

- Single depot case, all the m salespersons have to start and end at a given single depot.
- m depots case, every salesperson have to start and end at their own depot.
- $2m$ depots case, every salesperson have to start and end at their own 2 depots, i.e., starting and ending depot are different for every salesperson.
- >1 and <$2m$ depots case, it is hybridization of above specified cases.

Obviously, depending on the MTSP version, a tour in MTSP can be an open or a closed path (cycle).

Like several previous works on MTSP, in this paper, we have considered the single depot case, i.e., all salespersons have to start and end their tour in the same city called depot, and followed the principle that every salesperson must have to visit at least one city in addition to the depot, i.e., every tour has a non-zero tour length. We have considered two objectives for the MTSP problem. The first objective is to minimize the total distance traveled by all the salespersons, i.e., minimizing the sumtotal of the tour lengths of all the salespersons. The second objective is to minimize the maximum distance traveled by anyone salesperson. The main idea behind this objective is to balance the workload among all salespersons. Throughout this paper, we will refer to the first objective as objective1, and, to the second objective as objective2. Both these objectives of the MTSP are $\mathcal{NP}$-Hard as for $m = 1$, they reduce to the TSP which is $\mathcal{NP}$-Hard [1]. The MTSP is more difficult than the TSP because first we have to find which cities to assign to each

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http://dx.doi.org/10.1016/j.asoc.2014.09.029
1568-4946/

salesperson, and then the optimal ordering among the cities assigned to each salesperson.

Compared to TSP, a wider range of real world problems specially those pertaining to scheduling and routing reduce to MTSP, e.g. print press scheduling [2], pre-print advertisement scheduling [3], bank crew scheduling [4], workload balancing [5], school bus routing [6], and designing satellite surveying systems [7]. Despite of this fact, only few approaches exist in literature to solve MTSP. Tang et al. [8] proposed a genetic algorithm (GA) with one-chromosome representation for MTSP problem and solved the hot rolling production scheduling problem using it. Malmborg [9] and Park [10] used a two-chromosome representation in their genetic algorithm based approaches for the vehicle scheduling problem (VSP). This representation can be adapted for MTSP also. Carter and Ragsdale [11] proposed a genetic algorithm using a new two-part chromosome representation and related genetic operators. Brown et al. [12] proposed a grouping genetic algorithm to solve MTSP by deriving chromosome representation and genetic operators from the grouping genetic algorithm proposed in [13]. Actually, MTSP is a grouping problem, i.e., a problem which seeks an optimal assignment of entities (cities in case of MTSP) according to a given objective function into different groups (tours in case of MTSP) subject to some constraints. Grouping genetic algorithms [13] are tailor-made for solving grouping problems. Both Carter and Ragsdale [11] and Brown et al. [12] have shown the superiority of their proposed approaches by comparing the results of their respective approaches with those of the two genetic algorithms that use one-chromosome and two-chromosome representations. Singh and Baghel [14] proposed another grouping genetic algorithm using a different chromosome representation and different crossover & mutation operators. This genetic algorithm used steady-state population replacement method instead of the commonly used generational model. This genetic algorithm outperformed all the previous approaches on both the objectives on the benchmark instances considered in [11,12]. Liu et al. [15] presented an ant-colony optimization (ACO) algorithm for solving the MTSP. This ACO uses a combination of pheromone values and information regarding the distance among cities to construct tours. It also employs a local search that uses both inter-tour and intra-tour operators. Inter-tour operators modify more than one tour simultaneously in a bid to improve the solution, whereas inter-tour operators works on a single tour at a time. Computational results had shown this ACO algorithm to be competitive with other approaches on both the objectives. Recently, Yuan et al. [16] proposed a new crossover operator called two-part chromosome crossover (TCX) for solving the MTSP using a genetic algorithm and showed its superiority over the genetic algorithm of Carter and Ragsdale [11] only. They have also reported the results of their proposed approach on some new instances. Though, they have not compared their approach with those in [14,15], their results are inferior to these approaches. Bektas [17] provides an excellent survey on exact and heuristic solution approaches to the MTSP and its variations, and their real world applications.

A lot of swarm intelligence based approaches have been proposed in the literature to solve TSP (e.g. [18–25]). However, very few swarm intelligence based approaches exist in the literature for MTSP. To our knowledge, the ACO approach of Liu et al. [15] described in the previous paragraph is the only swarm intelligence based approach for the MTSP. In addition, Ghafurian and Javadian [26] presented another ACO approach for solving a variation of MTSP where they have considered the multi-depot case and imposed lower and upper bounds on the number of cities that a salesperson can visit and the objective was to minimize the total distance traveled by all the salespersons. Both these approaches are based on ACO only. Absence of any other swarm intelligence based approach for the MTSP and the success of ACO approach of Liu et al. [15] in solving the MTSP (as mentioned already, results obtained through this approach are comparable with those obtained with any other state-of-the art approach on both the objectives) has motivated us to develop new swarm intelligence based approaches for the MTSP.

In this paper, we have proposed two new swarm intelligence based metaheuristic approaches for the MTSP. Our first approach is based on artificial bee colony (ABC) algorithm, whereas the second approach is based on invasive weed optimization (IWO) algorithm. In fact, two slightly different versions of ABC algorithm have been presented in this paper. In the first version, neighboring solutions are generated more or less at the same distance from the original solution throughout the execution of ABC algorithm, whereas in the second version, the expected distance of the neighboring solution from the original solution is gradually reduced from a pre-defined initial value to a pre-defined final value over the iterations of the algorithm. Our ABC and IWO approaches are designed keeping in mind the grouping nature of the MTSP. The solutions obtained through these approaches are improved further through a local search. The performance of the proposed approaches is compared with the state-of-the-art approaches on both the objectives. Computational results clearly show the superiority of all our proposed approaches over existing approaches.

The rest of this paper is organized as follows: Section 2 provides an introduction to the artificial bee colony algorithm. Section 3 describes our ABC approach to the MTSP problem. Section 4 provides an introduction to the invasive weed optimization algorithm, whereas Section 5 describes our IWO approach to the MTSP problem. Computational results are presented in Section 6. Finally, Section 7 provides some conclusions and directions for future research.

2. The artificial bee colony algorithm

The artificial bee colony (ABC) algorithm is a recent metaheuristic technique developed by Karaboga [27] on getting inspiration from the intelligent foraging behavior of natural honey bee swarm. Entomologists classify the foraging bees into *scout*, *employed* and *onlooker* bees depending on the function they are performing currently. Scout bees look for new food sources in the vicinity of the hive. As soon as a scout bee finds a food source, this scout bee is reclassified as employed bee. Employed bees are responsible for collecting the nectar from food sources and bringing it to hive and sharing information about their food sources with the onlooker bees. Onlooker bees wait in the hive for employed bees to share information about their food sources. To share the information with onlooker bees, the employed bees perform dances in a common area in the hive, which is called dancing area. Through dance, an employed bee convey vital information regarding its food source such as the direction in which it is located, distance from hive, and nectar amount of food source. Onlooker bees watch numerous dances before selecting a food source. The probability with which an onlooker bee selects a food source, is proportional to nectar amount of that food source. If the nectar amount of a food source is good, more onlooker bees will choose that food source. After performing the dance in the dance area the employed bee goes back to its food source along with all those onlooker bees which chose this food source Once an onlooker starts exploiting a food source, it is reclassified as an employed bees. When a food source is completely exhausted, all the employed bees associated with it leave it, and become scouts or onlookers. Hence, the scout bees do the job of exploration, whereas the employed and onlookers bees do the job of exploitation.

Motivated by this intelligent foraging behavior of honey bees, Karaboga [27] proposed the ABC algorithm in 2005. ABC algorithm