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A Study on Combinatorial Optimization Problems Using Ant Colony Optimization Algorithms

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Abstract—

Ant colony optimization (ACO) has been widely used for different combinatorial optimization problems. It is called a metaheuristic technique and which is part of the swarm intelligence. ACO is based on the behaviors of ant colony and this method has strong robustness as well as good distributed calculative mechanism. ACO has very good search capability for optimization problems. One of the most famous combinatorial optimization problems is travelling salesman problem with help ACO has been proven a successful and promising result and this technique applied for number of combinatorial optimization problems. In this paper, we have study on overview of the ACO algorithm and review of the few optimization problems and their applications using ant colony optimization algorithms which have been addressed promising results and those are presented.

Keywords—Antcolony optimization algorithm, combinatorial optimization problems, applications.

I. INTRODUCTION

The ACO algorithm was proposed by Marco Dorigo in 1992. It is a part of swarm intelligence which is the research field which studies algorithms inspired by the observation of swarms [1]. Optimization algorithms inspired by ants have been initially proposed to solve combinatorial optimization problems (COP). Examples of COPs include vehicle routing and course timetabling [2]. Combinatorial optimization deals with finding optimal combinations or permutations of available problem components. Therefore, it is required that the problem is partitioned into a finite set of components, and the various combinatorial optimization algorithms applied to find their optimal combination or permutation. Examples of some established ACO algorithms are Ant System (AS), ANTS, Ant System by ranking (ASRank), ANT-Q, Ant Colony System and the MAX-MIN Ant System (MMAS) [3].

The field of ‘‘ant algorithms’’ studies derived from the observation of real ants’ behavior, and uses these models as a source of inspiration for the design of novel algorithms for the solution of optimization and distributed control problems. The main idea is that the self-organizing principles which allow the highly coordinated behavior of real ants can be exploited to coordinate populations of artificial agents that collaborate to solve computational problems and the behavior of aspects in ant colonies have inspired different kinds of ant algorithms. Examples

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are foraging, division of labor, brood sorting, and cooperative transport. In all these examples, ants coordinate their activities via stigmergy, a form of indirect communication mediated by modifications of the environment [15].

A. ACO Algorithm

The ant colony optimization algorithm (ACO), was formulated by Marco Dorigo in 1992.It is a Meta heuristic algorithms for optimizing complex problems and it is a probabilistic technique that searches for optimal path based on ants behavior from source to food. ACO algorithm is one of the most successful Meta heuristic approaches and widely recognized algorithmic based on the ant behavior.

- Ants move from nest to food resource.
- They discovered the shortest path based on pheromone deposition.
- The paths are selected randomly.
- If pheromone deposition is more than one path the probability of that path selection will be increased. When an ant moves from point source to destination, ant makes pheromone trails, to mark these paths with helps of the other ants to find the way passed by their team members as they check pheromone trail and choose, in probability, the paths having greater concentration of pheromone [4].

B. ACO Metaheuristic

Ant colony optimization is a metaheuristic in which colony of ants cooperate in finding good solutions to difficult discrete optimization problems. ACO algorithms can be used to solve both static and dynamic combinatorial optimization problems. A metaheuristic is a set of algorithmic concepts that can be used to define heuristic methods applicable to a wide set of different problems.

A metaheuristic is a general algorithmic framework which can be applied to different optimization problems with relatively few modifications to make them adapted to a specific problem. Examples of metaheuristic include simulated annealing (Cerny´, 1985; Kirkpatrick, Gelatt, & Vecchi, 1983), tabu search (Glover, 1989, 1990; Glover & Laguna, 1997), iterated local search (Lourenc¸o, Martin, & Stu¨tzle, 2002), evolutionary computation (Fogel, Owens, & Walsh, 1966; Holland, 1975; Rechenberg, 1973; Schwefel, 1981; Goldberg, 1989), and ant colony optimization (Dorigo & Di Caro, 1999b; Dorigo, Di Caro, & Gambardella, 1999; Dorigo, Maniezzo, & Colorni, 1996; Dorigo & Stu¨tzle, 2002) (see Glover & Kochenberger [2002] for a comprehensive overview). The use of metaheuristic has significantly increased the ability of finding very high-quality solutions to hard, practically the relevant combinatorial optimization

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problems in a reasonable time. This is particularly true for large and poorly understood problems [15].

The paper is organized as follows. In the next section the key note on combinatorial optimization problems. The next section 3 the overview of the some optimization problems which are used to ACO algorithm. In section 4 the overview of the applications in ACO Algorithm the followed by next section our conclusion and references.

II. COMBINATORIAL OPTIMIZATION PROBLEMS

Combinatorial optimization problems are finding values for discrete variables with the optimal solution and the given objective function is found. Many optimization problems of practical and theoretical importance are of combinatorial nature. Examples are the shortest-path problems as well as many other important real-world problems like finding a minimum cost plan to deliver goods to customers, an optimal assignment of employees to tasks to be performed, a best routing scheme for data packets in the Internet, an optimal sequence of jobs which are to be processed in a production line, an allocation of flight crews to airplanes, and many more. A COP is either maximization or a minimization problem which has associated a set of problem instances. The term problems have several parameters or variables with unspecified values. The term instance refers to a problem with specified values for all the parameters [15].

III. OVERVIEW OF THE OPTIMIZATION PROBLEMS TYPE USING ACO ALGORITHMS

A. Ant Colony Optimization Algorithms for the Traveling Salesman Problem

Traveling salesman problem (TSP) is a most popular and extensively studied problem in the field of combinatorial optimization and attracts computer scientists, mathematicians and others. It is one of the most challenging problems in operational research. It also an optimization problem of finding a shortest closed tour that visits all the given cities. It is known as a classical NP-complete problem, which has extremely large search spaces and is very difficult to solve.

The TSP is also plays an important role in ACO research: the first ACO algorithm, called Ant System. Many of the ACO algorithms has proposed subsequently and those are first tested by TSPs. ACO has been widely applied to solving various combinatorial optimization problems such as traveling salesman problem (TSP), job-shop scheduling problem (JSP), vehicle routing problem (VRP), quadratic assignment problem (QAP), etc. [6.3]. Although ACO has a powerful capacity to find out solutions to combinatorial optimization problems and the traveling salesman problem (TSP) is the problem of finding a shortest closed tour which visits all the cities in a given set. In a symmetric TSP the distance between two cities is the same direction of travel

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whereas in the asymmetric TSP the distance is different direction of travel. It has been symmetric TSPs in which cities are on a plane and a path (edge) exists between each pair of cities. The definition of a TSP is: given N cities, if a salesman starting from his home city and he has to visit each city exactly once and then return home, find the order of a tour such that the total distances (cost/time/money/energy etc) traveled should be a minimum. A complete weighted graph G= (N, E) can be used to represent a TSP, where N is the set of n cities and E is the set of edges (paths) fully connecting all cities. Each edge (i,j)∈E is assigned a cost dij, which is the distance between cities i and j [5].

B. Ant Colony Optimization Algorithms for the Vehicle Routing Problem

The vehicle routing problem can be designed as a combinatorial optimization problem. It is a finding optimal route for a fleet of vehicles performing assigned tasks on a number of geographically sectored clients. So solving this problem is the best route serving all clients using a fleet of vehicles, respecting all operational constraints, such as vehicle capacity and the driver's maximum working time, and minimizing the total transportation cost.

There are 3 main factors to define as model of the VRP: the road network, specifying the connection between the clients and depots, the vehicles, transporting goods between clients and depots on the road network; the clients, which has been place orders and receive goods. Joining the various factors of the problem, it can define a whole set of different VRPs [6]. All these variants have been created in order to bring the VRP closer to the kind of situations faced in the real-world [7].

Based on these elements the first ACO algorithm to be proposed was Ant System (AS) [8]. It is organized in two main stages: construction of a solution, and update of the pheromone trail. Since its publication different variants have been proposed to improve the solutions of combinatorial optimization problems: elitist ant system [9], rank-based ant system [10], and Max – Min ant system [11] are variants, where the algorithm differs from the original mainly in the pheromone update rule. The next view of the, extensions of AS display more substantial changes in the algorithm structure. Ant Colony System (ACS, [12]) is one of them. ACS differs from AS for a revised rule used in the tour construction algorithm, and the use of both local and global updates of the pheromone trails. ACS has been shown to be very efficient in solving problems of the vehicle routing class, ranging from the static case to the dynamic case. In the ACO has been applied in a number of cases to solve real world logistic problems.

IV. APPLICATIONS OF OPTIMIZATION PROBLEMS USING ACO ALGORITHMS

Here described some of the application used to ant colony optimization algorithm and the given promising results and these applications are summarized in chronological order table 1.

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A. *Improved Travelling Salesman Problem Using Ant Colony Optimization*

This paper is made one of the typical bio-inspired algorithms for TSP. This algorithm is driven by the Ant colony optimization with the introduction of a new parameter. By using ant colony optimization algorithm setting a new parameter to find the shortest path by getting rate of evaporation of pheromone level in time t using vector coordinates, directly by assigning the given value for alpha, beta it can know the amount of pheromone level evaporated and length of the path traveled in time t by using vector coordinate analysis. Thus, by this can get the near shortest path traveled in time t and which further gives a way to its destination point.

B. *Modified Ant Colony Optimization Algorithm for Multiple-vehicle Traveling Salesman Problems*

In this work, an extended the original Traveling Salesman Problem (TSP) and this case of multiple vehicles but also to constrain the minimum and maximum numbers of cities each vehicle can visit. The algorithm is a modified Ant Colony Optimization (ACO) algorithm which has the ability to avoid local optima; the algorithm can be applied to transportation problem that covers either a single vehicle or multiple vehicles. The original ACO added a new reproduction method and a new pheromone updating strategy, and then four improved local search strategies. To be tested our algorithm on several standard datasets in the TSP library. Its single-vehicle performance was compared to that of ant system (AS) and elitist ant system (EAS) algorithms. Its multiple-vehicle performance was evaluated against that of ant colony system variants reported in the literature. In this proposed ACO's single-vehicle performance was superior to that of AS and EAS on every tested dataset and its multiple-vehicle performance was excellent.

It has been improved ant system algorithm which was especially effective for the multiple-vehicle routing problem. It used four local search strategies: simulated annealing (SA), simulated annealing with similarity measure (SA_Sim), 2-opt, and 3-opt. Performance of the proposed algorithm was assessed on several single-vehicle TSP and MTSP instances from the TSPLIB. For single vehicles, it converged closer to the global optimum solutions than both AS and EAS. For multiple vehicles, it outperformed other ACS variants in 11 out of 16 datasets. Our future work will attempt to further improve the ability of searching the global optimum and make it applicable to larger datasets as well as to multiple depots [13].

C. *Ant Colony Optimization using Genetic Information for TSP*

In this study proposes an Ant Colony Optimization using Genetic Information (GIACO). The GIACO algorithm combines Ant Colony Optimization (ACO) with Genetic Algorithm (GA).

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GIACO searches solutions by using the pheromone of ACO and the genetic information of GA. In addition, two kinds of ants coexist: intelligent ant and dull ant. The dull ant is caused by the mutation and cannot trail the pheromone. A GIACO applied to Traveling Salesman Problems (TSPs) and it confirms that GIACO obtains more effective results than the conventional ACO and the conventional GA.

The proposed Ant Colony Optimization using Genetic Information (GIACO) is optimizes the tour of TSP not only pheromone but also the genetic information as GA. GIACO is composed of the intelligent ants and the dull ants, and the dull ants are caused by the mutation of GA. It has investigated the performances of GIACO by applying it two TSPs. They have confirmed that GIACO including the dull ants obtained better results than GIACO which containing only the intelligent ants because the dull ants help in getting out of the local optima.

D. Improvement in Ant Colony Optimization using Routing in MANET

Ant Colony Optimization is a technique of solving computational problems and to find the optimized paths through graph. It is an optimization technique roused from the extraordinary behavior of Ants in nature. This algorithm is a probabilistic technique stochastic. The ACO algorithm is well balanced for good exploration and exploitation most of the times. The method through which data is send from a sender to a specific destination is known as routing. It provides the connection between two or more nodes in a network. In this a routing protocol is proposed roused by the Ant Colony Optimization. Our routing protocol is designed using NS2.

E. Dynamic Flying Ant Colony Optimization (DFACO) for Solving the Traveling Salesman Problem

This paper presents an adaptation of the flying ant colony optimization (FACO) algorithm to solve the traveling salesman problem (TSP). This new modification is called dynamic flying ant colony optimization (DFACO) was originally proposed to solve the quality of service (QoS)-aware web service selection problem. Many researchers have addressed stagnation problem from the TSP. In FACO, a flying ant deposits a pheromone by injecting it from a distance; therefore, not only the nodes on the path but also the neighboring nodes receive the pheromone. The amount of pheromone a neighboring node receives is inversely proportional to the distance between it and the node on the path. In this work, it has modified the FACO algorithm to make it suitable for TSP in several ways.

For example, the number of neighboring nodes that received pheromones is varied depending on the quality of the solution compared to the other solutions. This helped to balance the exploration and exploitation strategies. It also embedded the 3-Opt algorithm to improve the solution by mitigating the effect of the stagnation problem. Moreover, the colony contained a combination of regular and flying ants. These modifications aim to help the DFACO algorithm is achieved better solutions in less processing time and avoid getting stuck in local minima. This

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work compared DFACO with ACO have five different methods using 24 TSP datasets and parallel ACO (PACO)-3Opt using 22 TSP datasets. It has achieved the best results compared with ACO and the five different methods for most of the datasets (23 out of 24) and then quality of the solutions [14].

Table 1. Applications are listed by class of problems in chronological order [16].

Problem name	Authors	Algorithm name	Year
Traveling salesman	Dorigo, Maniezzo & Colorni	AS	1991
	Gambardella & Dorigo	Ant-Q	1995
	Dorigo & Gambardella	ACS & ACS-3-opt	1996
	St¨utzle & Hoos	MMAS	1997
	Bullnheimer, Hartl & Strauss	ASrank	1997
	Cord´on, et al.	BWAS	2000
Quadratic assignment	Maniezzo, Colorni & Dorigo	AS-QAP	1994
	Gambardella, Taillard & Dorigo	HAS-QAPa	1997
	St¨utzle & Hoos	MMAS-QAP	1997
	Maniezzo	ANTS-QAP	1998
	Maniezzo & Colorni	AS-QAPb	1999
Scheduling problems	Colorni, Dorigo & Maniezzo	AS-JSP	1994
	St¨utzle	AS-FSP	1997
	Bauer et al.	ACS-SMTTP	1999
	den Besten, St¨utzle & Dorigo	ACS-SMTWTP	1999
	Merkle, Middendorf & Schmeck	ACO-RCPS	2000
Vehicle routing	Bullnheimer, Hartl & Strauss	AS-VRP	1997
	Gambardella, Taillard & Agazzi	HAS-VRP	1999
Connection-oriented	Schoonderwoerd et al.	ABC	1996
Network routing	White, Pagurek & Oppacher	ASGA	1998
	Di Caro & Dorigo	AntNet-FS	1998
	Bonabeau et al.	ABC-smart ants	1998
Connection-less	Di Caro & Dorigo	AntNet & AntNet-FA	1997
Network routing	Subramanian, Druschel & Chen	Regular ants	1997

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	Heusse et al.	CAF	1998
	van der Put & Rothkrantz	ABC-backward	1998
Sequential ordering	Gambardella & Dorigo	HAS-SOP	1997
Graph coloring	Costa & Hertz	ANTCOL	1997
Shortest common Supersequence	Michel & Middendorf	AS-SCS	1998
Frequency assignment	Maniezzo & Carbonaro	ANTS-FAP	1998
Generalized assignment	Ramalhinho Lourenc¸o & Serra	MMAS-GAP	1998
Multiple knapsack	Leguizam´on & Michalewicz	AS-MKP	1999
Optical networks routing	Navarro Varela & Sinclair	ACO-VWP	1999
Redundancy allocation	Liang & Smith	ACO-RAP	1999
Constraint satisfaction	Solnon	Ant-P-solver	2000

V. CONCLUSION

In this paper we have noticed Ant Colony Optimization has been continues to be a fruitful paradigm for designing effective combinatorial optimization solution algorithms and also ACO one of the most successful paradigms in the metaheuristic area. Finally these overviews have addressed about few combinatorial optimization problems which are used to ACO algorithm. It has help to improving the performance and finding good results to be applied the different applications.

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