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A Survey of Ant Colony Optimization

P. Sivakumar
Information Technology
Manakula Vinayagar Institute of Technology
Puducherry, India

K. Elakia
Computer Science and Engineering
Manakula Vinayagar Institute of Technology
Puducherry, India

Abstract— ***The research on the metaheuristic method which is known for its optimization, are initially focused on the proof – of –concept. The experimental work shows the practical interest of the method; whereas the knowledge can be deepen only through the theoretical concept. The method which is going to discuss is the ant colony optimization (ACO) which was introduced in early 90's, is a swarm intelligence technique inspired from the foraging behaviour of real ants. The ants deposit the pheromone for the identification of routes from nest to food for the other ants of same colony. This ACO exploits an optimization mechanism for solving discrete optimization problems in various engineering domains. In this paper we provide a survey on the ant colony optimization. Firstly, we review some basic concepts and application results. This technique attracts the interest of researchers and because of that many applications are done successfully. Finally, we review about the various recent researches which direct to gain deeper knowledge about ACO.***

Keywords— ***Metaheuristics, ACO, swarm intelligence, discrete optimization problem.***

I. INTRODUCTION

Swarm intelligence is a quite new approach to problem solving that takes stimulus from the social behaviours of insects and of other animals. Particularly, ants have stimulated from a number of methods and techniques among which the most successful is the general purpose optimization technique known as ant colony optimization. Ant colony optimization (ACO) is the foraging behaviour of the ant species. These ants deposit pheromone in order to mark path that should be followed by other members of the colony. This technique exploits a similar mechanism for solving optimization problems. In the early 90's , when the first ACO proposed it was attracted by the number of researchers and they developed many successful applications. We are going to discuss this technique in theoretical basis [1].

Generally, ants move randomly for the food by laying down the pheromone which is basically chemical in nature. The following ants of the same colony wander randomly at first, instead of following the trail for searching the food. However, the pheromone starts to evaporate and the attractive strength become weaker if the ants fail to follow the same. Alternatively, when marched over the short path frequently the pheromone density becomes higher than the longer route and the ants then follows the pheromone trail. If there were no evaporation at all, the paths chosen by the first ants would tend to be too attractive to the following ones. In that case, the exploration of the solution space would be constrained. Thus, when one ant finds a good path from the nest to a food source, other ants are more expected to follow that path [2].

Deneubourg et al. [3] investigated the pheromone ant the ant behaviour by analysing with the double bridge experiment [see fig 1(a)] the bridge consists of equal length from the nest to the food source. The ants start to find food by travelling the both bridge of equal length by laying the pheromone. After sometime one of the bridge finds to more concentrated and the remaining ants follows that path. Goss et al. [4] introduced the variant of the double bridge, where one bridge is longer than the other. The pheromone was found to be less evaporated in shorter bridge than the longer one. So they all take the path of shorter bridge. [See fig 1(b)]. From the characteristics and behaviour of the real ant colonies, the artificial ant system is developed to solve the combinatorial (CO) problems. According to Papadimitriou et al. [5] a CO problem p = (s, f) is an optimization problem, where s is called search space and f is the objective function $f : S \mapsto R^+$ which assigns positive cost value to each of the solution and to find either the minimum cost or the approximate solution.

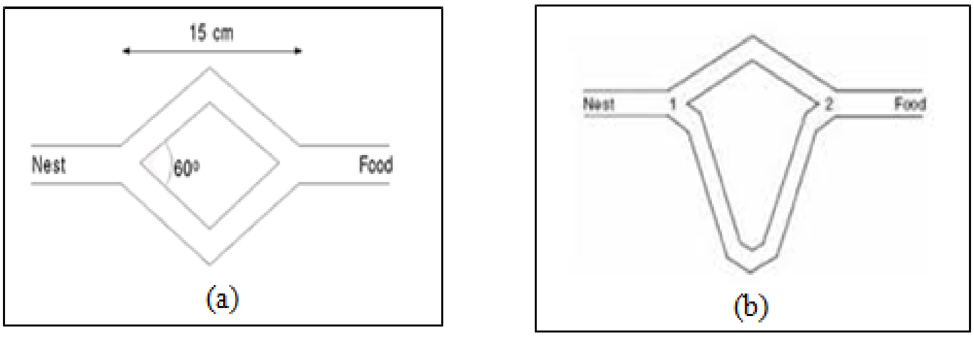

Fig. 1(a) Bridges of equal length (b) Bridges of different length

The solution that are found to be in reasonable amount time, treated as good solution. ACO algorithm belongs to the metaheuristics so it satisfies the later goal. The pheromone model is the central component in ACO algorithm which is also a probabilistic model. The pheromone model consists of vector of model parameter T called the pheromone trail parameters. The pheromone trail model Ti $\in$T, associated with the component of solutions, have value τ i called pheromone values. This model generates the probabilistic solution to the problem under consideration and to find the finite set of solution by assembling them. At run time the pheromones are updated by the previously generated solutions. The aim of updating is to concentrate on the where will get the good solution. The different ant colony optimization has been proposed some of them are listed below.

Table 1- List of successful ant colony algorithms

ALGORITHM	**AUTHORS**	**YEAR**
ANT SYSTEM(AS)	DORIGO ET AL.	1991
ELITIST AS	DORIGO ET AL.	1992
ANT-Q	GAMBARDELLA & DORIGO	1995
ANT COLONY SYSTEM	DORIGO & GAMBARDELLA	1996
MAX-MIN AS	STUTZLE & HOOS	1996
RANK-BASED	BULLNHEIMER ET AL.	1997
ANTS	MANIEZZO	1999
BWAS	CORDON ET AL.	2000
HYPER-CUBE AS	BLUM ET AL.	2001

All the ant colony algorithm has the similar ideas, only thing is that they are presented through different examples. Section II gives the general travelling sales man problem by applying the ACO, and the formal description of ACO.

II. OPTIMIZATION TECHNIQUE

A) Travelling Salesman Problem Using ACO

The concept of the travelling salesman problem is to travel between the set of cities. The aim is to find the shortest route provided that each city must visited once. That is the Hamiltonian tour of minimal connected route of completely connected graph. Similarly, in the ant colony optimization the problem is to tackle to the route; the vertex represents the cities and the connection between the two cities is the edge. The ants lay the pheromone in the edges to travel to the next vertex, following ants follows the same path. Notable that each city should be visited once. In fig 2. The probability that if j has not been visited, it can selected with the probability that is propositional to the pheromone with that edge (i,j). At the end, the quality of the pheromone is calculated between different vertex and edge to find the best solution.

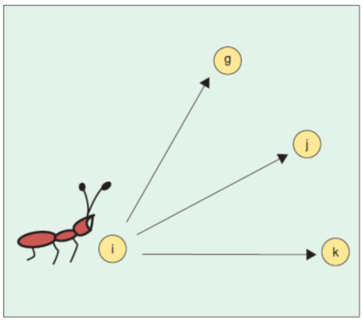

Fig. 2 Probability of choosing the city

B) The ACO metaheuristic

The metaheuristics is a general purpose algorithm that is the problem independent. It takes a few samples set of solution and made assumption over that and the final solution can be applied to varieties of problems. Example of metaheuristics are stimulated annealing[6], tabu search[7] and ant colony optimization. This includes two rules:

1. Local pheromone update while constructing the solution.
2. Global pheromone update, after the ants construct the solution.

A combinatorial optimization problem

A model $P = (\mathbf{S}, \Omega, f)$ *of a combinatorial optimization problem consists of:*

- *a search space* $\mathbf{S}$ *defined over a finite set of discrete decision variables* $X_i,\ i = 1, \ldots, n$;
- *a set* Ω *of constraints among the variables; and*
- *an objective function* $f : \mathbf{S} \to \mathbb{R}_0^+$ *to be minimized.*[2]

The generic variable X_i *takes values in* $\mathbf{D}_i = \{v_i^1, \ldots, v_i^{|\mathbf{D}_i|}\}$. *A feasible solution* $s \in \mathbf{S}$ *is a complete assignment of values to variables that satisfies all constraints in* Ω. *A solution* $s^* \in \mathbf{S}$ *is called a global optimum if and only if:* $f(s^*) \leq f(s)\ \forall s \in \mathbf{S}$.

Fig. 3 A Combinatorial Optimization Problem

III. ALGORITHM

The role of ant colony optimization is to search for the path that is more optimal by travelling between the source and the destination within a reasonable amount of time.

procedure Ant colony optimization
Set Initialize parameters, pheromone trails
while (termination condition not met)
do
Construct Ant Solution
Update Pheromone Trails
Daemon Actions
end
end

Fig. 4 General algorithm of ACO

The algorithm that is shown in fig .4; after initializing the parameters and pheromone trail, the ant construct the solution by managing the colony of ants, which concurrently and asynchronously visits the adjacent states to solve the problem of constructing solution. The ants search the solution by applying the local decision making policy which make use of trails and the heuristic information. By this way, the ants build the solution. Once the solution is build or being built, the ants evaluate the partial solution which will be used to update the pheromone trail, to find the deposition of pheromone. Update pheromone trail where the modification are done by the way of updating. There is chance of increase or decrease in the deposition of the trail, due to the pheromone evaporation content. The less the evaporation of the pheromone, the more the probability of the connection used by ants and good solution is produced, which will again used by the following ants. Daemon action is a centralized action which cannot be performed by single ant. That is the local or the global information, used to bias the search process from other non-local perspective [2].

IV. MAIN ACO ALGORITHM

There are several ACO algorithm has been proposed. But the familiar and the original ant system is the Max-Min ant system (MMAS) and the Ant Colony System (ACS).

A) Ant system (AS)

AS is the first proposed algorithm. The main characteristic of this algorithm is that the pheromone value is updated at each iteration itself by all the ants involved. Many algorithms has been developed having this as the basic structure [8].

B) Max-Min Ant System (MMAS)

MMAS is the best performing ACO algorithm for the Travelling salesman problem and Quadratic assignment problem. This was mainly developed to meet these requirements. The first thing is that to exploit best solution that is found during run time or during iteration of the algorithm, one single ant adds pheromone after each iteration. That may be the iteration-best ant, found during current iteration or global-best ant, found at the beginning of the solution. Secondly, the limit of interval $[\tau_{min} - \tau_{max}]$ range is set to avoid the stagnation at each possible stage. Finally, we initialize the pheromone trail to τ_{max}, to achieve the solution at the start of the algorithm [9].

C) Ant Colony System (ACS)

This is the combinatorial optimization based on real ant behaviour. They introduced a local pheromone update where the updation is done at the end, also called offline updation. Each ant performs the local pheromone update after each construction step. The ants perform different action during one iteration depending upon the pheromone [10]. But only one ant update the solution at the end whether it is iteration –best or best-so –far.

V. APPLICATION OF ANT COLONY OPTIMIZATION

The art of using the ACO in scientific community and other domains has peaked. The main theme of choosing this algorithm is that it will produce the high quality solution. Because it is successfulness they have employed in different domains like industries, computational intelligence and also in real- world application.

A) Telecommunication Networks

ACO algorithm was known to be the effective algorithm for the routing technique in telecommunication networks. They were applied to the routing problems in both circuit switched and packet switched network. Circuit switching is based on telephone network and the packet switching is based on the local area network. The concept provided by Schoonderwoerd et al., the ant-inspired algorithm works well with the wired networks. Hence the ant-based routing algorithm worked well with the wired and ad hoc networks [11][12].

B) Industrial Application

The ACO is a boon to the academic side, whereas the industrialist started to make use of this algorithm. The one make use of this algorithm first is the EuroBios, they have applied the ACO algorithm to number of scheduling problems like flow shop; example aluminium casting centre. The problem includes is to maintain the real-world capabilities, managing and auditing. Bautista et al applied this algorithm for assembling the balancing problem and constraint between tasks [13].

Table. 2 List of applications

PROBLEM TYPE	PROBLEM NAME
Routing	Travelling Salesman Problem Vehicle Routing Sequential Ordering
Assignment	Quadratic Assignment Course Timetabling Graph colouring
Scheduling	Project Scheduling Car Sequencing
Subset	Set Covering Multiple Knapsack Maximum Clique
Machine Learning	Classification Rules Bayesian Network Neural Networks
Bioinformatics	Protein Folding DNA Sequencing

C) NP- Hard problem

The usefulness of the metaheuristic technique is to apply to a number of problems and compare its performance with other techniques. In this way, ACO already tested in TSP. subsequently, NP-hard problems also considered. ACO has been tested with more than hundreds of different NP-hard problems. Some of the tackled problem are considered, they are; routing problem arise in the distribution of goods, assignment problem, set of objects has to be assigned to given number of location subjected to some constraints. Scheduling problem, subset problem and so on. ACO has been applied in the fields of bio-informatics and machine learning [14].

VI. ALGORTHMIC DEVELOPMENT

During the early years of ACO research, they were focused in developing ACO variants which modify the pheromone update or the different solution generation to improve algorithmic performance. Recently researchers have started to use the combination of ACO with other algorithmic technique. Here, we review about the recent developments.

A) ACO with Constraint Programming Techniques

Meyer and Ernst [15] proposed a constraint programming for solving the hard constraints problems. Some problem have high constraints and difficult to find the feasible solution. Finding an alternative way is the integration of constraint programming (CP) technique into ACO. This method would lead to find the solution earlier whether the solution is feasible or infeasible. This is tested over the highly constrained scheduling problem shows the potential result.

B) Hybridization of ACO with Branch and Bound

This method is the combination of ACO with the tree search technique, example branch and bound. Approximate nondeterministic tree search (ANTS) by Maniezzo[16] used the lower bound estimates as heuristic information for finding attractive solution components. The lower bound computation allows the method to prune the feasible solution if the estimated solution cost is larger than the best solution. The computational result obtained with the ANTS for the quadratic and frequency assignments are very promising.

C) Hybridization of ACO with other Metaheuristics

The method of hybridization of ACO with local heuristic used to fine-tune the solutions which are created by ants. Usually simple iterative algorithms are used. One example is tabu search used for the improvement of QAP. Another hybridization method is used, where the ants find the solution from the partial not from the beginning. The advantages of solution construction from the partial solution are (1) the construction of solution is faster (2) the best solution may be exploited directly.

VII. CONCLUSION

Ant colony optimization algorithm whose first member is the Ant system, initially proposed by Dorigo et al. The underling idea was inspired from the real ant's behaviour. Later those characteristics are applied in the artificial system, and the response was good enough throughout the researchers. The system plays a vital role in solving the combinatorial problems. The ACO concept used for goods propagation process helps in finding effective and systematic procedure finding the best path for propagation of goods optimally with predefined cost and constraint functions. They adaptively modify the path and find the best solution by comparing relatively. Then started to apply for the optimization problems ends up in good result. The study of how to apply the ACO in different platforms will be a big research issue. A better understanding of the theoretical features of ACO will lead to better research. And it has been proved for solving the combinatorial problems. The future work is to put different ideas to develop this algorithm.

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