Ant Colony Optimization in solving the Vehicle Routing Problem(VRP)

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***Abstract*— The application of meta-heuristic method of Ant Colony Optimization(ACO) in solving the Vehicle Routing Problem(VRP) is investigated in this study which finds the optimum route with cost efficiency. The behavior of ants colonies using ACO algorithm has been reviewed on four different papers right from the year where the ACO was introduced to solve VRP in 1991, followed by the review for consecutive four decades. These papers showcase the ACOs adaptability, efficiency and potential in handling the multifaceted logistics and routing problems. The first paper introduces the ACO for TSP followed by a hybrid ACO-2-opt heuristic approach in solving VRP in the second paper. In the third paper, ACO is employed to solve multiple routes and the fourth paper employs the use of ACO for FVRP, highlighting its efficiency in optimizing delivery routes in urban areas.**

Keywords—Vehicle Routing Problem, Optimization, pheromone trail, cost saving, evaporation, Ant Colony Optimization.

I. Introduction

Heuristic originates from Greek word which means to 'find' and the heuristic and metaheuristic techniques contribute by providing a sufficiently satisfactory solution to complex optimization problems. The main aim behind heuristic is to give solution to a problem in hand with a reasonable time frame and hence the solutions given are the approximate results and not the actual algorithm. The solution given needn't be the best solution of all but it is still of importance as it does not demand an excessively long time. Heuristics play an important role in the field of Artificial Intelligence(AI) in which they are useful in situations where there could be problems for which no known algorithms are available and heuristics provide problem solving strategies that guide decision making and help in finding solutions, with no optimality guaranteed.

The term metaheuristic was named by Fred Glover and it can be regarded as a master strategy which oversees and manages other heuristic methods thereby, instead of using a single fixed heuristic, the process is handled dynamically. The metaheuristics uses a tradeoff of randomization and local search and by interacting with other heuristics, it aims higher in finding solutions which wouldn't be normally possible by those heuristics alone. These algorithms have been introduced to tackle problems of non-linearity, uncertainty, multi-objective and so on as they provide optimum solution with ease. The success lies in their most important feature of need of a) minimal requirement for additional knowledge on the optimization problem and b) numerical robustness of the ACO algorithms.

The Ant Colony Optimization(ACO) was introduced by Marco Dorgio in 1990. It is a metaheuristic algorithm which has been widely used in solving various optimization problems led by the inspiration from the behavior of real ant observation where the concept of pheromone based communication is applied mimicking the biological ant colonies. ACO is a swarm intelligence method and is based on the behavior of ants seeking a path between their colony and a source of food. In real scenario, when the the ants finds food randomly, they returns to their colony leaving behind pheromone trails which is likely to be followed by other ants in the colony. These pheromone trail eventually evaporates and hence the strength reduces. As a result, the ants find the shortest path by comparison of travels and thereby the pheromone density becomes higher on shorter paths compared to the longer ones. This influence of pheromone evaporation allows to find the optimum distance between the food and its colony.

This idea of natural behavior in ants was converted into finding the shortest distance in an weighted graph. The main three steps are a) pheromone initialization b) tour construction and c) pheromone update. During the first phase of each iteration, every ant probabilistically finds a solution by determining the sequence to traverse the edges within the graph. In the next phase, the paths taken by different ants are contrasted with each other and the last step involves updating the levels of pheromones present on each edge of the graph. The application of ACO begun for solving the Water resource problem that couldn't be solved using Genetic Algorithm(GA) and has been an alternative to GA as the results established good efficiency and had the ability to find the global optimal solution. The ACO is an effective approach in finding solution to the vehicle routing problem and in this survey, we are going to see the application of ACO in addressing routing problems and its development since 1980 to 2020. The review is based on four research paper starting from the introduction of ACO for optimization, followed by applications of ACO on three more routing problems. The review and analysis of these four papers are outlined below.

II. Review

Distributed Optimization by Ant Colonies(1991) - A. Colorni, M. Dorigo, and V. Maniezzo

The Traveling Salesman Problem (TSP) is a optimization problem where the aim is to find the optimum path with minimum distance and less cost. The authors in this paper focused on solving the TSP using ACO[1], a novel approach. This distributed problem-solving approach is taken inspiration by the behavior of ant colonies. Even with limited capacities in individual ants, the ant colonies demonstrate structured behavior through interactions among individual ants. This phenomenon is exhibited by the animal kingdom at large and is exceptionally observed in ants. This natural behavior helps in solving the optimization problems effectively.

The ants communicate with each other via pheromone trails, leading to find the shortest path between the ant's colony and its food source. Pheromone trails lead to autocatalytic behavior, in which, more the ants take a route, the more attractive it becomes for other ants. However, the shortest route is not always the feasible option and alternative exploration of routes are required for optimal solution. The increase in complexity will rise to high computational cost but this paper presents that the increasing the agents leads to high efficiency of the overall system as well as the individual agent.

This paper proposes a distributed problem approach where the simple interacting agents(ants) communicate locally, thereby contributing in solving complex problems collectively. Three ant characteristics of the ant cycle algorithm is introduced here a) ANT-density, b) ANT-quantity and c) ANT-cycle. These exhibits unique usage of pheromone quantities and updating the trail intensities. The ANT-quantity and ANT-density algorithms use pheromone quantities in guiding the ants movements. Parameters settings like the trail sensibility 'a', distance travelled 'b', evaporation rate 'r', and pheromone quantities 'Qh' or 'Q3' are set and these parameters contribute to the quality of the solution. Simulations conducted on small sized(10 cities) and large problems(30, 50, and 75 cities) shows that the parameter settings impact the performance of the algorithm significantly. In the ANT-cycle, an different approach is taken where the pheromone is updated only after the completion of the tour instead of each ant's move and the value of the trail intensity is updated in every 'n' steps. This approach outperformed the other two, mostly on the larger problems. Here, the ANT-quantity and ANT-density algorithms was mostly sensitive to parameter 'b' and ANT-cycle algorithm was sensitive to parameters a, b, r and Q3. It is seen that the efficiency decreases with increase in agents.

Overall, it is seen that the autocatalytic process pressed by a greedy force gave optimal solution by showing suboptimal path with exponential speed. However, the greedy force alone was not able to do anything except for finding the optimal path.

Applying the ANT System to the Vehicle Routing Problem(1999) - B. Bullnheimer, R. F. Hartl, and C. Strauss

The Vehicle Routing Problem(VRP) has been a complex optimization problem in the field of research since the 1950s because of its importance in distribution systems. As there is no known polynomial algorithm for VRP in finding the optimal solution, it is considered NP hard. Various metaheurestic algorithms including genetic algorithms, tabu search, simulated annealing have been employed in addressing the VRP. The VRP and TSP share a close relationship in which the VRP is broken into several TSPs when solving the routing problem and hence in this paper[2], to find the route with lowest travel expense, the TSP ant system proposed in our previous research by Colorni et al.is used.

The authors in this paper aim to solve the VRP problem to find the route with lowest travel expense using hybrid Ant System algorithm making use of TSP in VRP, incorporating the 2 opt heuristic for tour improvement with problem specific information such as cost savings and capacity utilization. The problem involves capacity and distance constraints, a central depot, and identical vehicles. Elitist ants are introduced here to enhance the performance of Ant system in solving the VRP. In the Ant system for VRPs, the problem is represented by a weighted directed graph. This system includes the selection of customers by artificial ants based on the visibility and pheromone trails and the vehicle routes are constructed while keeping in mind that the customer demands are satisfied considering the vehicles capacity. In the hybrid approach, 2-opt heuristic for tour is combined with Ant system with the introduction of the concept "savings" to estimate the benefits of merging two cities into a single route. This method improved the solution quality due to the capacity utilization and savings. In the problem specific improvements, capacity utilization concept has been introduced, where the vehicle was to be effectively utilized and elitist ants and parameter settings were done to influence the selection probabilities. The author emphasizes that the arrangement of two cities in relation to each other helps in knowing the tour length where the order in which the cities are visited are of greater importance for optimization. Here, while selecting the next cities to be visited, the algorithm selects the cities in such a way that there is high savings associated to it which means that the cities are chosen which offer the potential for cost-efficient routes.

The proposed methodology achieved impressive solution for the VRP, however failed to improve the best-known solutions for fourteen specific test problems. Nevertheless, in practical scenario, uncertain travel costs, demands, and service times leads to 5% of deviations and hence this paper provided a significant improvement in solving the VRP problem compared to our earlier study and is well suited for parallel implementation. However, it is worth noting that the increase in the number of ants used for computations has remained constant. Yet, the tabu search algorithm is deemed better in comparison and for further improvement, parameter settings must be tuned with detailed analysis on the methodology used.

Ant colony optimization techniques for the vehicle routing problem(2004) – J.E. Bell and P.R. McMullen

Finding optimal routes in logistics is important in business and extensive research has been carried out to find the optimal delivery route and using limited delivery vehicles for supply to save time and cost. In this paper[3], the authors have applied the metaheuristic method of ACO where modification are made to ACO in solving the traditional TSP allowing the search of the multiple routes of the VRP. This method shows its effectiveness as solutions were got within 1% deviation from the known optimal solutions. Also, the concept of multiple ant colonies yielded better results in solving larger and more complex problems. Also, the candidate list size employed in the method influences the quality of solutions generated significantly.

In this method, the route construction is done where the ants simulate the vehicles by selecting customers incrementally based on a probabilistic formula taking into consideration pheromone levels on paths and distances. The vehicles return to the depot after all the customers are visited. In updating the trial, pheromone trails are updated for improved solutions which includes local updating to simulate evaporation of pheromone trails to prevent taking the same path all over again and global update to favor the shortest routes with high pheromone levels. For route improvement strategy within vehicles, a local exchange procedure using 2-opt heuristic is employed where the candidate list determines the next location which contains the closest location. Here, multiple ant colonies are introduced for differentiating different routes for different vehicles.

The simulation was done on single and multiple ant colony and where applied on three problems varying in size with exceptional results obtained when n=50 for both. However when n=100, the best results were found with candidate size 14. This shown that ACO showed optimum results within 1% of optimum for smaller problems and were efficient for larger problems only when candidate size was introduced. Also with the increase in number of individual vehicles, having separate ant colonies and separate pheromone trails for each vehicle is beneficial and candidate list size is important for finding optimum solution in VRP. However, to improve the ACO efficiency for larger problems, ranking methods must be combined.

Solving the feeder vehicle routing problem using ant colony optimization(2019) - Y. H. Huang, C. A. Blazquez, S. H. Huang and others

Feeder Vehicle Routing Problem (FVRP) is a new type of delivery vehicle implemented for fast delivery in urban areas which consists of small vehicles like motorbikes and large vehicles like trucks. The motorbikes are sent along with the trucks for expediting the delivery of smaller parcels and they meet with trucks in certain customer locations called joints for reloading due to limited capacity. Here trucks are depots as well as customer serving vehicles and these heterogeneous vehicles ensure that interdependency exists between their routes. The research by authors in this paper[4] have utilized ACO for determining the number of dispatching sub-fleets and finding optimal routes to minimize the fixed route and travel costs.

In this methodology, sub-fleets are identified and initial solutions are built with attraction functions for direct vehicle movement. The pheromone levels are updated, and if required. Here, the algorithm's complexity depends on the number of customers (N), ants (A), and iterations (I), with an O(N2) time complexity. This method is found to produces effective solutions by optimizing urban delivery routes for various vehicle types. Also, it is notable that cost is reduced if the two vehicles travel in the same route.

To validate the ACO performance, three types of benchmark datasets were generated and examined. The distribution of customers location showed to have a greater impact with cost and appeared higher for random customer locations. Also, 36 instances of the FVRP and VRP were used to compare the outcomes of the ACO technique. Despite the longer overall distances, FVRP showed cost savings ranging from 7.6% to 39.5% when compared to the VRP. From this, we could infer that ACO algorithm performs better in terms of computational time and cost efficiency when compared to a hierarchical heuristic. It offers promising solutions within manageable deadlines, even when its costs are higher than ideal results for small scenarios, especially for higher customer quantities.

III. Conclusion

The objective of this study was to investigate heuristic and meta heuristic algorithms in solving various optimization problem and Ant Colony optimization has been selected to in addressing the Vehicle Routing Problem. The review has been studied on four different papers spanning four decades from 1990 with the initial review on the introduction of ACOs application on TSP where variation of ACO was employed and parameter sensitivity played a major role in finding the solution. The hybrid approach in the second paper stood out for its practical application of ACO to the VRP. It demonstrated improved performance over the existing solution and emphasized parameter tuning for improved performance. The third paper considered application of ACO on multiple routes and introduced the impact of candidate's list size on solution quality. It demonstrated higher performance with larger VRP scenarios. The fourth paper was unique where ACO was applied for FVRP with heterogeneous vehicles to optimize the route and cost in urban areas. This method provided a specialized solution in tackling complex delivery scenario with both small and large vehicles.

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