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Comparative Analysis of Bio-Inspired Algorithms for Underwater Wireless Sensor Networks

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Abstract

Mobile nodes in underwater wireless sensor networks are becoming very important as they not only enable flexible sensing areas but also entails the ability to provide means for data and energy sharing among existing static sensor nodes. In this paper, three efficient meta-heuristic evolutionary algorithms ant colony optimization, artificial bees colony and firefly algorithm, inspired by swarm intelligence are being compared with an objective to achieve the shortest path for the mobile node in traversing the complete sensing network. We transform this problem into the traveling salesman problem. It is the most famous and commonly used nondeterministic-polynomial combinatorial optimization problem in which an artificial agent is set to travel between different cities and calculate distance or time consumed to travel between these nodes or cities for best route selection. Heuristic and meta-heuristic algorithms are being used for decades to solve such type of problems. In this comparative study, an analysis of meta-heuristic algorithms for obtaining results in less processing time while searching for the optimal solution has been done. Moreover, this paper provides a classification of mentioned algorithms and highlights their characteristics. The experiment has been carried out on these algorithms by manipulating different parameters such as population and number of iteration.

Keywords Underwater wireless sensor network (UWSN) · Meta-heuristics · Evolutionary algorithms · Traveling salesman problem (TSP) · Swarm intelligence (SI) · Non-deterministic polynomial-hard problem (NP-hard) · Combinatorial optimization problem (COP) · Ant colony optimization (ACO) · Artificial bees colony (ABC) · Firefly algorithm (FFA)

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1 Introduction

Unlike traditional static wireless sensing network that can only opportunistically perform sensing tasks at a fixed location, mobile sensing nodes offer *direct control* over *where* to sample the environment [1]. They can thus realize sensing functionality previously beyond reach, such as exploring near-inaccessible areas [2], or inspecting the seafloor to gain fine-grained environmental data [3]. Especially for underwater wireless sensing, where environmental conditions are very hard and communication is very unreliable, the mobile sensing nodes can act as energy and information carrier to increase the lifetime of the existing network.

Most of the existing research efforts focused on traversing the sensor network in a periodic and deterministic manner. However, as in the real-world deployment, environmental conditions never remain constant, a fixed path for these mobile nodes is not a practical solution.

Observing the limitation of existing solutions, we investigate three different optimization algorithms to determine the shortest path for the mobile node at runtime. There are two categories in which optimization algorithms are divided: deterministic and stochastic algorithm [4]. Heuristic and meta-heuristic algorithms are types of stochastic approach in which there is some randomness, that means they take different routes and ways to find the best solution. Heuristic algorithms are problem dependent techniques for solving any particular type of problem while meta-heuristics are an advanced form of heuristic approach and mostly use randomization and local search, based on the iterative improvement of a solution [5]. Heuristic and meta-heuristic algorithms have been designed in AI to solve different optimization problems. Such kind of problem is also known as nondeterministic polynomial time(NP-hard problem) [6]. Algorithms like ant colony optimization (ACO), artificial bees colony algorithm (ABC), firefly algorithm (FFA) and many more are the examples of the meta-heuristic technique.

The reason behind choosing these algorithms for comparison is their joint categorization as Bio-inspired technique specifically derived from insects family, having the same behavior and pattern for doing any job and solving any problem. To compare their performance parameters it is important to understand how they actually work? In this paper, a common issue of traveling salesman problem (TSP) has been chosen to obtain results in less processing time by simulating all three algorithms.

This paper focuses on processing time improvement while finding the optimal solution in any complexed Combinatorial optimization problem (COP), in our case its shortest path for mobile node, solved by three different algorithms. COP is a topic consists of finding an optimal result from a set of finite or infinite possible results. The main attention of combinatorial optimization problems is to focus on the efficient utilization of resources. Issues like Vehicle routing problem, Physical mapping, integrated circuit designing, scheduling problems, etc, can be found in COP [4]. Likewise, Traveling Salesman Problem is one of these problems that are easy and simple to explain but difficult to solve in polynomial time. It has finite nodes but an infinite solution of discovering a node.

To give a reader a little background, evolutionary algorithms and swarm intelligence approach are discussed in Sect. 2. Combinatorial problem is discussed in Sect. 3. In Sect. 4 simulation of mentioned algorithms and their results have been carried out. Finally, we conclude the paper with brief remarks in Sect. 5.

2 Evolutionary Algorithm and Swarm Intelligence

In artificial intelligence, algorithms for solving optimization problems can be categorized as a heuristic approach or meta-heuristic approach. Evolutionary algorithm (EA) is a subfield of evolutionary computation, which is a field of artificial intelligence. It is a meta-heuristic approach works on exploitation and exploration. Meta-heuristic algorithms are stochastic in nature that means it has some randomness in constraints and it is problem independent. These algorithms can further be classified by observing the nature of a problem. It could be linear or non-linear [7]. Furthermore, the algorithm can be classified as a single-agent algorithm like simulated annealing [7] or multi-agent algorithm like genetic algorithms, bio-inspired algorithms, and nature-inspired algorithms, that is based on population. Figure 1 shows the components that each EA has.

Swarm intelligence is bio-inspired technique [6] for solving complex problems. Many species like birds, insects, fish, etc, were kept in a confined area where their natural and social behavior for solving any problem and handling any obstacle was observed and implemented in the form of algorithms [5, 8]. Swarm intelligence technique is being widely used nowadays for solving complex problems in many areas because it portrays self-organization behavior of different flocks of birds, bees, insects and other animals [5].

2.1 Ant Colony Optimization

Ant colony optimization (ACO) derived from swarm intelligence [9] is the most popular and general technique used for solving optimization problems. ACO is a meta-heuristic algorithm inspired by the nature of ants and their working methodology for searching for food [9, 10].

In ACO, ants move in search of food and their target is to find the best and shortest path to the destination. Ants start to move in different possible directions from their nest, leaving pheromones behind for other ants to follow the trails of deposited pheromones [9]. As pheromones evaporate with time, higher the rate of pheromones, greater will be the number of ants following the path, lower rate of pheromones shows that the path chosen is

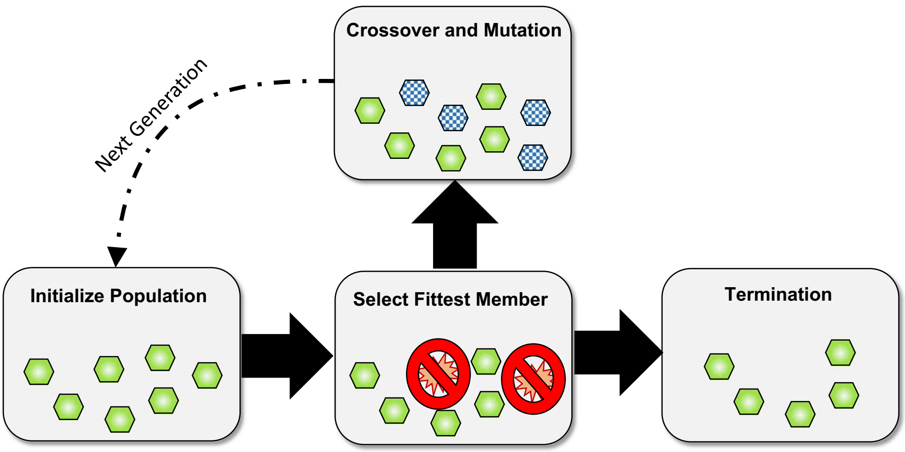

Fig. 1 Components of evolutionary algorithms

longer and smaller will be the number of ants following that path. In this way, ants reach the food by traveling through the shortest distance (Fig. 2).

Ants maintains a table in their memory to hold information calculated on each node. This information is spread forward to the other ants in the colony by deposited pheromones and they choose the path on the basis of higher probability. The probability for selecting a destination based on pheromone and heuristic values can be calculated by the following equation:

$$\Delta T_{ij}(t+1) = P.T_{ij}(t) + \Delta T_{ij} \tag{1}$$

$$\Delta T_{ij} = \sum_{k=1}^{l} \Delta_{ij}^{k} \tag{2}$$

where i = source location, j = destination location, k = ants and ΔT_{ij}^{K} = Intensity of Pheromone.

2.2 Artificial Bees Colony Algorithm

The artificial bee colony (ABC) is an optimization algorithm which also comes under swarm intelligence [11], is a meta-heuristic algorithm inspired by social behavior of natural bees for searching food.

In ABC whenever any bee finds the food source, it alarms the other bees by dancing in their particular style. This tells the other bees about the location of the food source guiding them in the direction towards good sources of food. These bees attract a large number of bees to search for the food area. In ABC, bees are divided into three categories: employed bees, onlooker bees and scout bees [11] as shown in Fig. 3.

Employed bees perform the local search and explore the neighboring locations of the food source based on the properties such as the taste of its nectar, amount of nectar and closeness to the hive. Then these bees share this valuable information with other bees

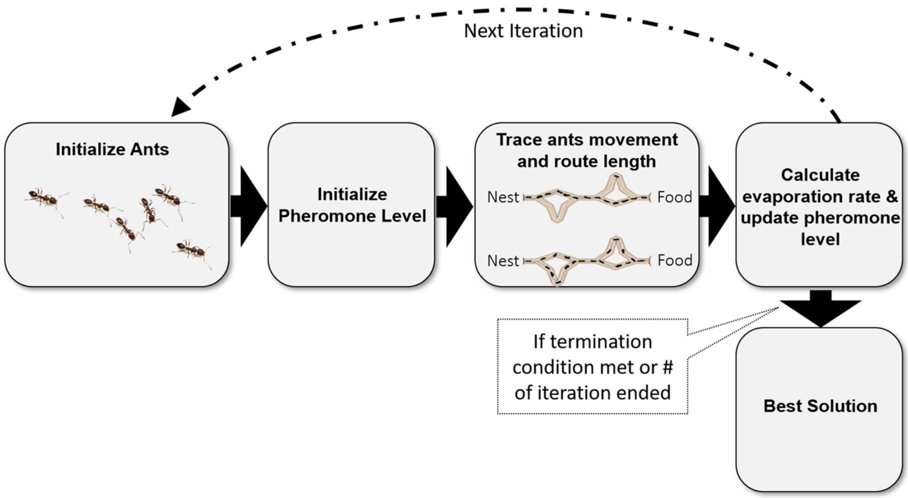

Fig. 2 Steps for ant colony optimization

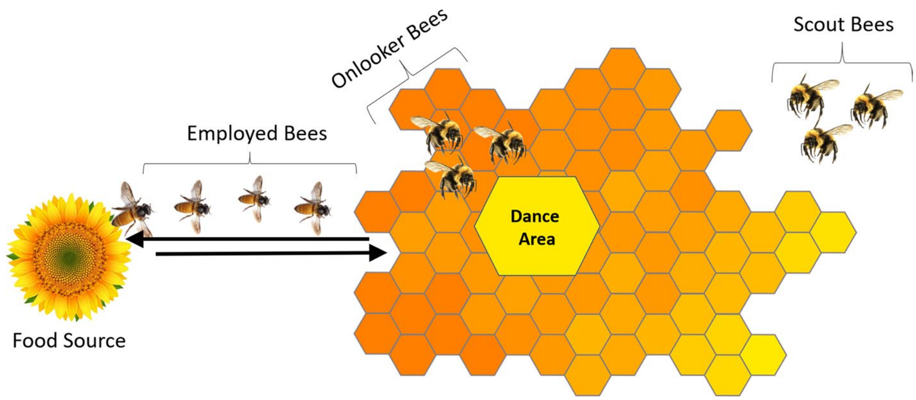

Fig. 3 Basic model of bee colony

waiting in the hive through the dance floor. Onlookers are the bees, waiting on the dance area to decide, based on the information available on the dance floor about all the current rich food sources, which food source to choose. They perform global search [11]. Whereas the scout bees are random in nature and searches randomly for the food, discovering new places which are undiscovered by the employed bees. In order to better understand the basic flow of ABC algorithm, Fig. 4 shows steps for ABC.

2.3 Firefly Algorithm

The firefly algorithm (FFA) is a meta-heuristic algorithm mainly use to solve production and scheduling problems [12]. The algorithm derives its inspiration from self organized behavior of fireflies.

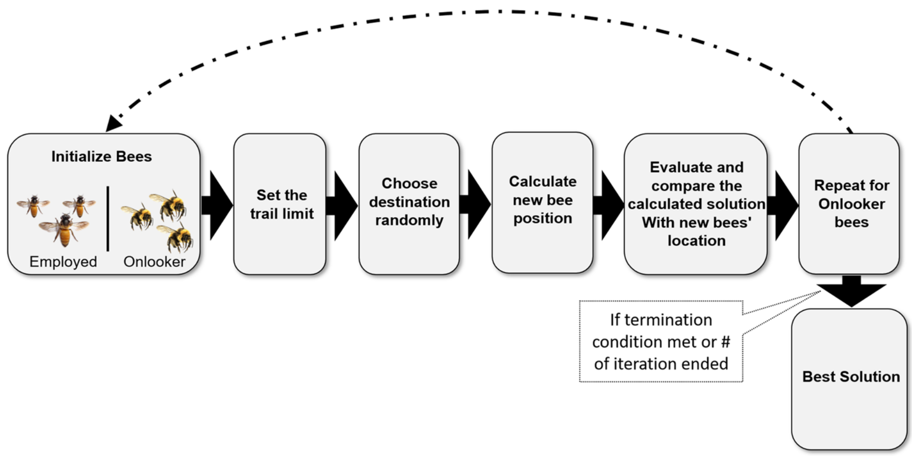

Fig. 4 Steps for artificial bee colony

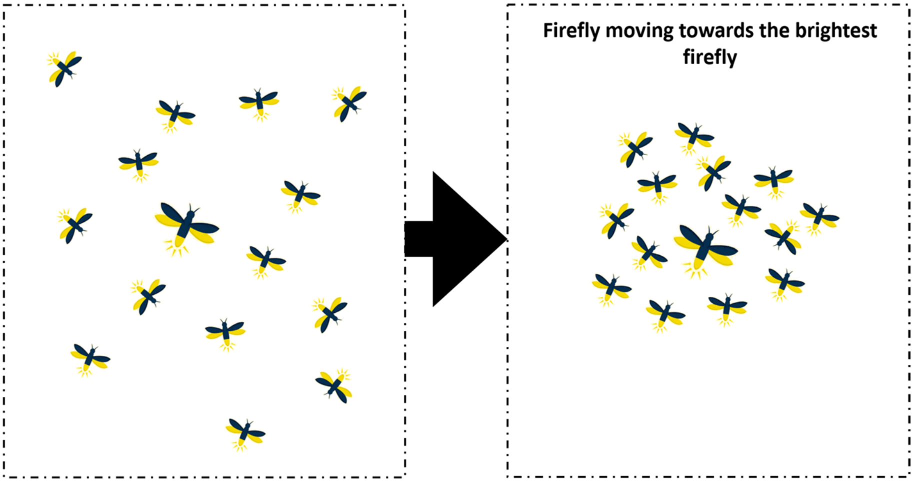

Fig. 5 Basic model for firefly algorithm

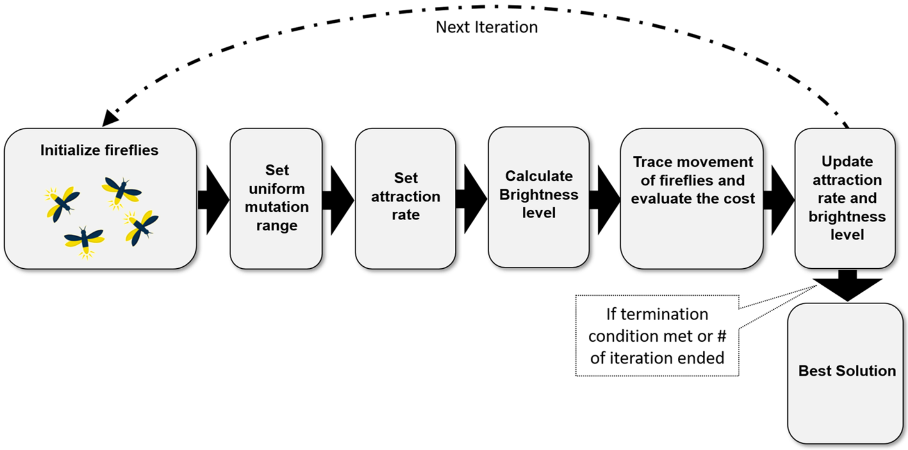

Fig. 6 Steps for firefly algorithm

In FFA all the flies are attracted by each other and their attractiveness is directly proportional to their brightness, as the distances between the fireflies increases, brightness reduces. Normally a fly with less brightness will move towards the brighter one as shown in Fig. 5. Flies will move randomly in case of the firefly having the highest brightness. If there is no firefly brighter than a given one, it will keep moving randomly until the condition meets. The main steps of the firefly algorithm are shown in Fig. 6.

3 Combinatorial Problem

Combinatorial optimization is a very complex problem to be solved for finding an optimal solution in many areas like production planning [13], scheduling of jobs in a multi-server environment, computer networking [4] etc. Traveling salesman problem (TSP), job-shop scheduling problem (JSP) and vehicle routing problem (VRP) are all combinatorial optimization problems [9] that can be efficiently solved by meta-heuristic algorithms.

In this paper, three meta-heuristic algorithms are being used to solve the traveling salesman problem. In TSP an artificial agent is set to find best possible path or route. Agent travels between different cities in search of an optimal solution and he has to visit all the cities at least once and reach the starting point again as one example shown in Fig. 7. It provides the best possible solution expressed as a set of nodes in the form of a graph.

It is considered that each of the city is connected to the other nearest city by any medium. The task is to find out the shortest path from the source city to the destination city, a problem occurs when there are thousands of cities or nodes involved. For such problem, TSP could be solved using heuristic and meta-heuristic algorithms. The general TSP formula is given by;

$$\min \sum_{i=1}^{n} \sum_{j!=1,j=1}^{n} (c_{ij}x_{ij}) \tag{3}$$

where $0 \leq x_{ij} \leq 1$, i = Source City, j = Destination city, c_{ij} = Distance between cities, x_{ij} = Path goes from city i to city j.

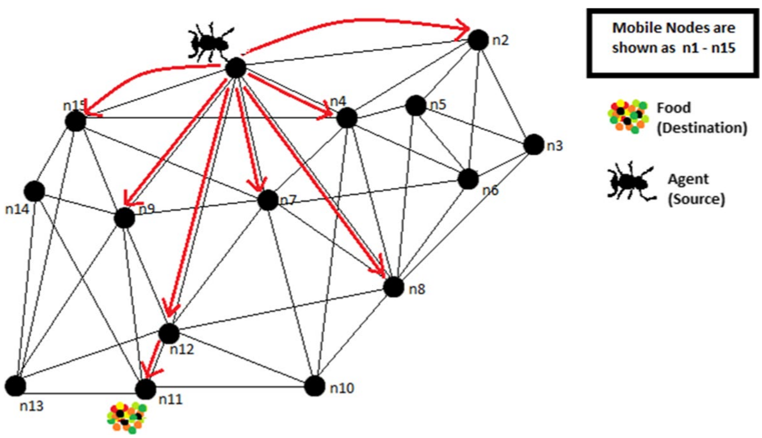

Fig. 7 Traveling salesman problem with n-complex nodes. Agent at node "n1" can choose multiple paths to reach "n11", but for returning to its original position it can't take the same path chosen for arriving the destination

4 Experiments and Results

The mentioned algorithms are compared below by TSP method using Matlab simulation tool, to show the best and shortest path as a solution. Total 4 sets are tested in the Figs. 8, 9 and 10 for each algorithm with varying number of iterations and population.

The mentioned algorithms are compared below by TSP method using Matlab simulation tool, to show the best and shortest path as a solution. Total 4 sets are tested in the Figs. 8, 9 and 10 for each algorithm with varying number of iterations and population (Figs. 11, 12, 13).

5 Conclusion

All the three algorithms are run to solve complexed combinatorial traveling salesman problem. TSP is use to find best(optimal) solution and in this paper processing time improvement is being measured only. Total four sets of experiments have been designed to evaluate the behavior of algorithms. Sets with more number of agents are providing better results. Similarly increasing the number of iterations is also improving the performance in all the three algorithms. It can easily be seen that for ACO and ABC, experiment set b and d are better than set a and c as we can see through results that in ACO, initially processing took 30 ms and 35 ms for set b and d, respectively and after iterations it reduces and consistent to 25 ms in both the sets. Similarly in ABC the initial processing time was 24 ms and 48 ms for set b and d but after iterations it becomes 3 ms and 2 ms, respectively, which means in ACO and ABC increasing the number of population is helping in improving performance of the algorithms. While for FFA, experiment set a is proved to be better than b, c and d as it can be seen

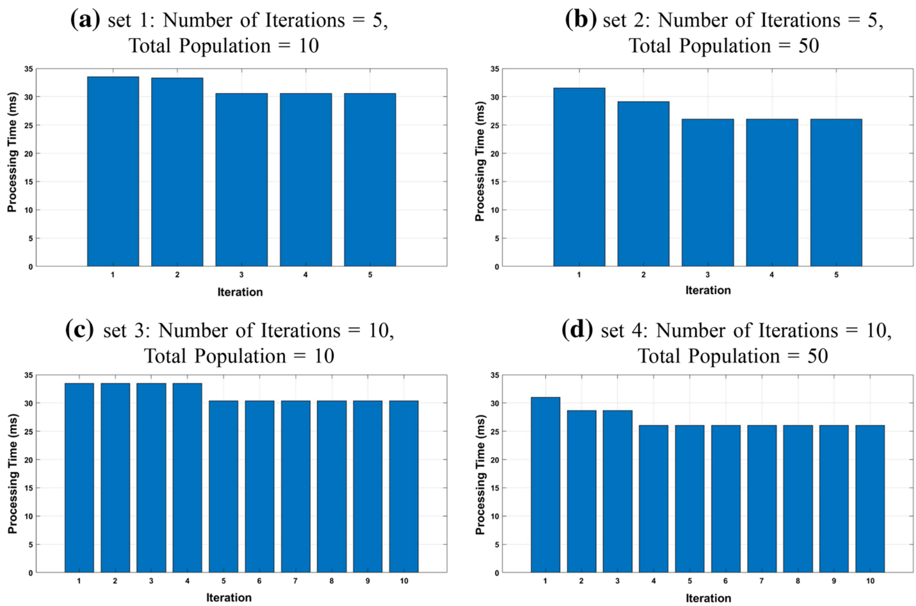

Fig. 8 ACO for optimal solution

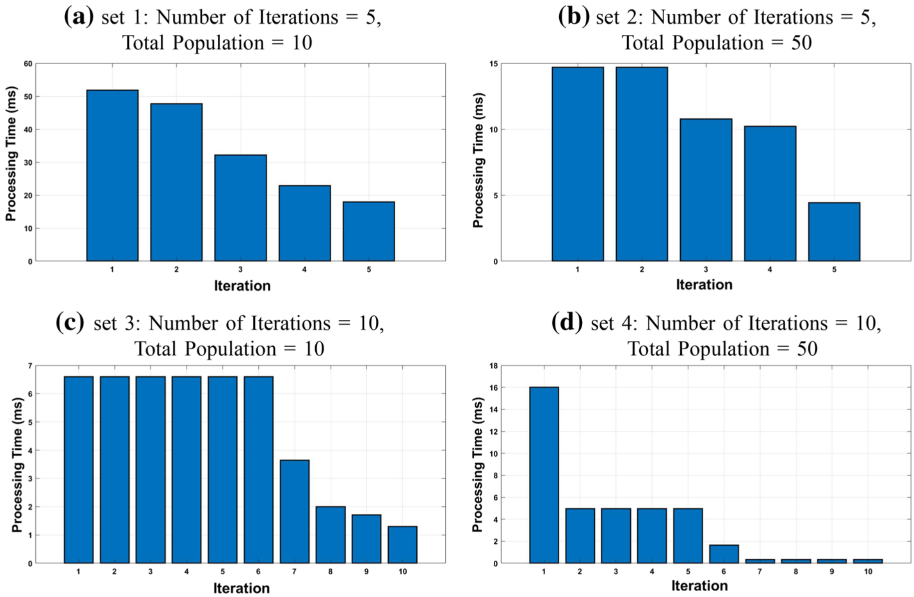

Fig. 9 ABC for optimal solution

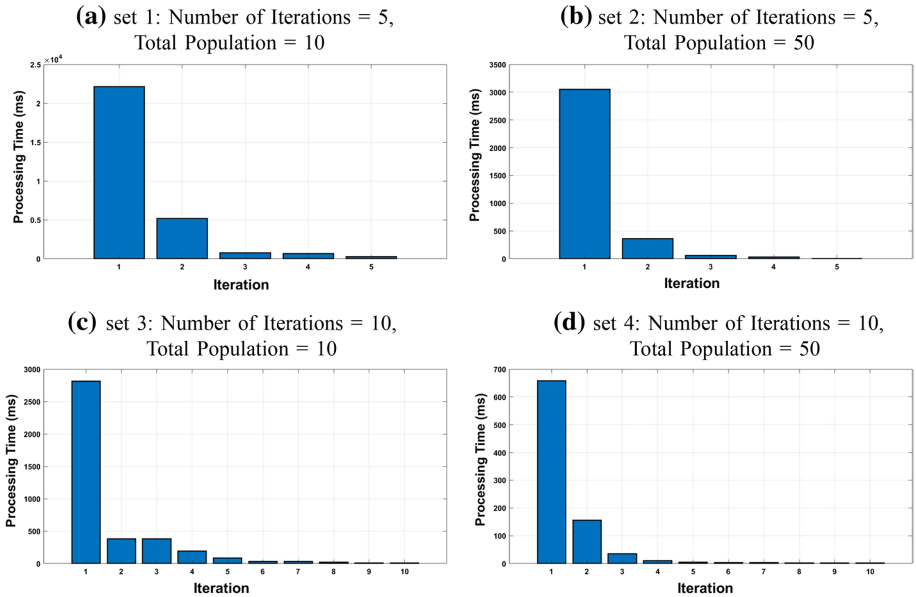

Fig. 10 FFA for optimal solution

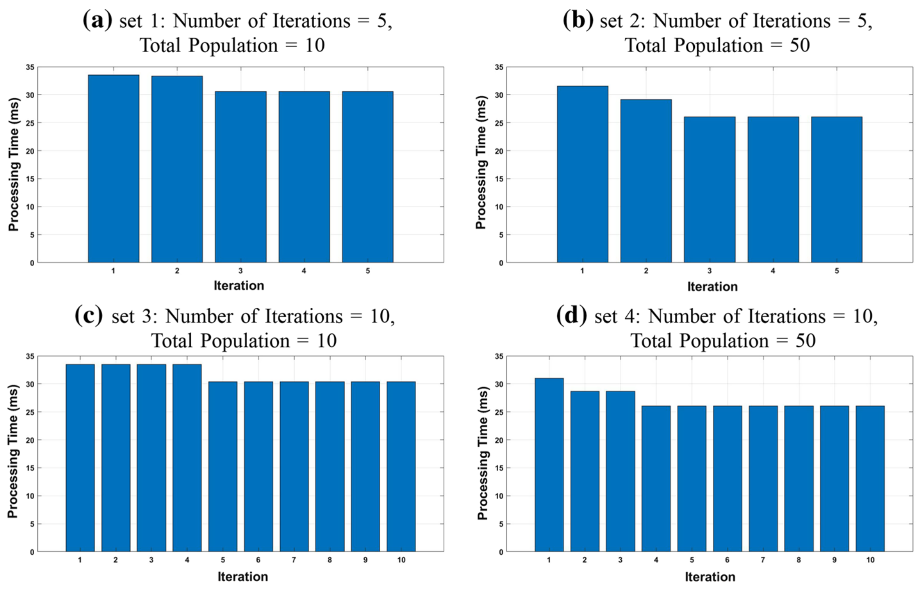

Fig. 11 ACO for optimal solution

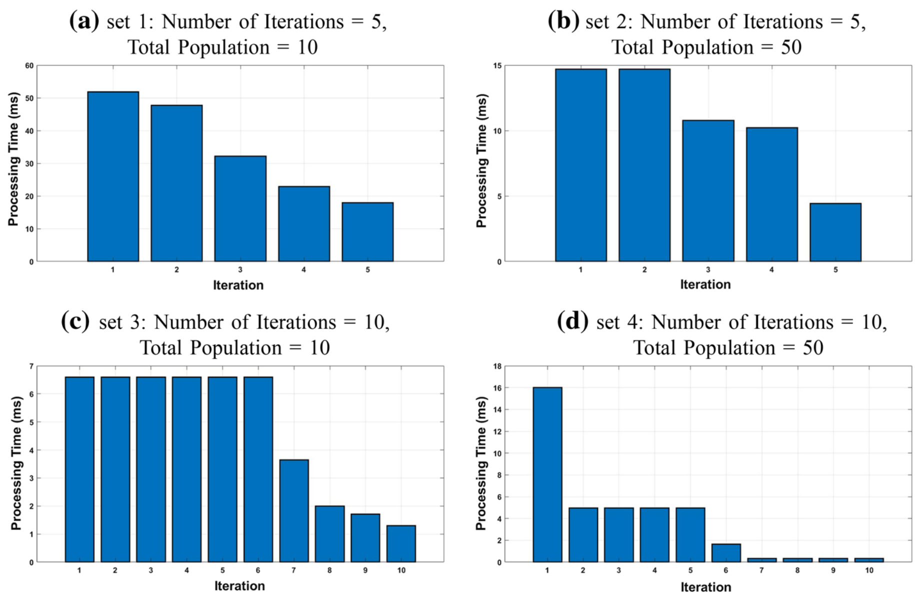

Fig. 12 ABC for optimal solution

that with less number of iterations and smaller quantity of population this algorithm is providing with the best result. However processing time for solving any complex task is getting improve and better with time as reaching to get the optimality, in all the algorithms and these results are showing processing time improvement in searching the optimal result of a system.

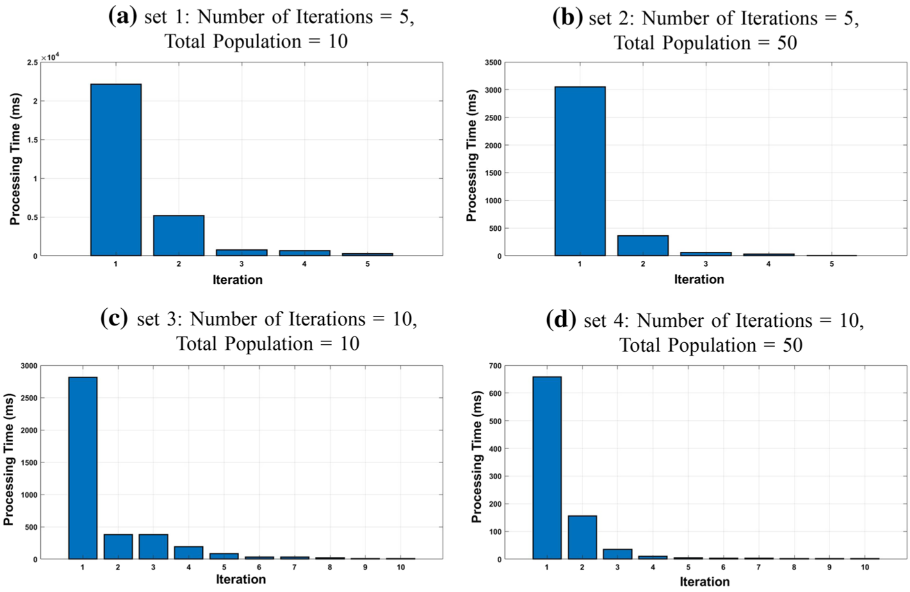

Fig. 13 FFA for optimal solution

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