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A Discrete Ant Lion Optimization (DALO) Algorithm for Solving Data Gathering Tour Problem in Wireless Sensor Networks

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Abstract: Lifetime of the wireless sensor networks is crucial in many of the mission critical applications. One way of improving the lifetime of the entire network is through proposing an optimal data gathering tour by the mobile sink to obtain information in the network. The mobile sink visits all the sensor nodes within the deployed region by traveling in a planned manner, collects the sensor data and forwards it to the base station for further processing. In the proposed work, the distance traveled by the mobile sink is minimized such that it collects the event details from all the sensor nodes in a quick and efficient manner. The data gathering tour taken by the mobile sink is modeled similar to a symmetric Euclidean Traveling Salesman Problem and a Discrete Ant Lion Optimization algorithm is proposed for optimally solving it. The simulations are carried out under different network conditions and the results show that the proposed algorithm shows better performance in terms of average tour length, accuracy and rate of convergence over the other existing approaches.

Key words: Wireless Sensor Networks · Discrete Ant Lion Optimization · Data gathering · Traveling Salesman Problem · Tour length · Mobile sink

NTRODUCTION

Wireless Sensor Networks (WSN) also known as Wireless Sensor and Actuator Networks (WSAN) are a network of autonomous sensor nodes that are compact in size. The sensor nodes are predominantly deployed without a preconfigured infrastructure in an unmanned environment to monitor various physical events like temperature, pressure, sound, vibration etc. [1]. Nowadays, WSN assists human life through various applications such as smart homes, precision agriculture, target tracking, intelligent buildings, disaster relief operations, facility management, medicine and health care, logistics, habitat monitoring and even a lot more [2]. Each sensor node in the WSN has its own built-in sensors, microcontroller, communication device, memory and power supply. The sensor nodes sense the various events in the deployed environment with their inbuilt sensors and process it using the onboard microcontroller and forward the event information to the sink node for further processing using single-hop/multi-hop communication [3].

WSNs are subject to the limited energy constraint because of the onboard battery which is not easy to replace in the unmanned remote environment. The lifetime of the WSNs is always based on the battery and its residual energy. Moreover, the energy of the sensor nodes deployed in the application environment will be consumed either for sensing the environmental parameters or for forwarding the sensor data to its neighbors through which data forwarded to the destination (sink node). The sink node may be static or mobile. If the sink is static, sensor nodes will deduce the best routing path to forward data to the sink. If the network has mobile sink, then a best path should be plotted for the sink node to collect data from all the nodes in the network with less distance. Data Gathering from the sensor nodes is one of the factors that significantly determines the lifetime of the WSN. Depending on the WSN application, the pattern and the frequency at which the sensor data have been collected will differ. In general, the data gathering can be divided into single-hop data gathering, multi-hop data gathering and mobile data gathering. In single-hop data gathering, the sensor nodes directly transmit the sensor data to the sink node located at the remote place with higher transmission power. This consumes more energy and reduces the lifetime of the entire network. In multi-hop data gathering, the sensor

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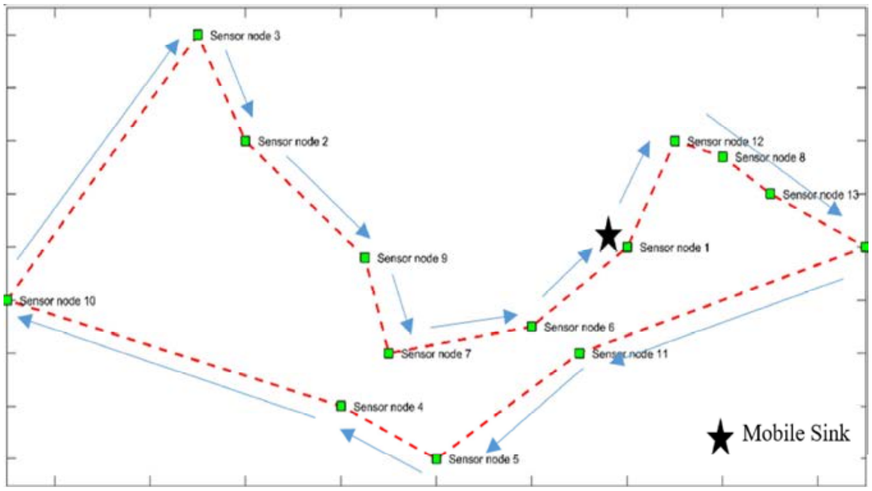

Fig. 1: A simple mobile data gathering model

nodes forward the data to its immediate neighbors (nodes that fall within radio range) with minimal power which in turn forward the received sensor data towards the sink node through numerous intermediate nodes using multiple hops that could improve the network lifetime. However, the sensor nodes close to the sink nodes die quickly (run out of energy) since it always receives sensor data from all the sensor nodes and directs towards the sink node. Sometimes it may also lead to network partition and information loss. In the mobile data gathering, the sink will move to the vicinity of all the sensor nodes and collect all their event data and finally uploads it to the base station. The mobile data gathering may involve either single mobile collector (the node that travels in a dedicated path to collect data from the sensors) or multiple mobile collectors that could ease the data collection process and improve the network efficiency. Mobile data gathering can be preferred over conventional data gathering in many applications due to its reduced energy consumption to collect the sensor data. Also, in order to further increase the energy efficiency of the mobile sink it may be equipped with energy replenishment schemes. The mobile sink node reduces the burden on the routing protocols at every sensor node through reducing the significant amount of energy spent at node to estimate the best routing path to reach the sink node, but incurs additional cost on the infrastructure designed [4, 5]. Figure 1 illustrates the data gathering by an mobile sink visiting each sensor node only once.

To improve the lifetime of the WSN, strategies that could efficiently use less energy at the sensor nodes are essential. Most of the existing research works exploited the energy of the sensor node through adaptive power control techniques, controlling the duty cycle of the transceiver, using energy efficient Medium Access Control (MAC) protocols, energy-aware routing protocols, data aggregation, clustering schemes etc. [6] in order to increase the energy efficiency, thereby increasing the lifetime of the network.

Dasgupta *et al*. [7] proposed a clustering based data collection and aggregation mechanism to improve the lifetime of the sensor network at the cost of increased delay in sensors. Ye *et al*. [8] proposed a dynamic routing scheme using generalized Ant Colony Optimization (ACO) to alleviate the data redundancy and network congestion in WSN. Here the performance is influenced by channel selection and energy consumption. Basagni *et al*. [9] proposed a heuristic based data gathering scheme in WSN. Here multiple mobile sinks are allowed to move randomly or stay in a static position and collect the data from sensor nodes eliminating the latency but it requires more infrastructures. Zhang *et al*. [10] proposed a polling based data collection in heterogeneous sensor networks, which avoided collisions at the cost of increased overhead and latency. Juang *et al*. [11] proposed a scheme in which the radio tagged zebras and whales are used as mobile nodes to collect the required data in a forest environment. But the mobility of the animals is hard to predict that ultimately lead to packet delay. Zhao *et al*. [12] proposed a Space Division Multiple Access (SDMA) based data gathering which reduces the data uploading time but at the cost of increased tour length. Yang [13] contributed a lot of nature inspired metaheuristic algorithms to solve various continuous optimization problems in various fields of engineering. Mirjalili [16] proposed Ant Lion Optimizer, a nature inspired optimization algorithm that mimics the hunting behavior of antlions. The algorithm provides competitive results for various mathematical functions, engineering problems and challenging constrained real problems in the world. The algorithm provides better results in terms of improved exploration of the search space, avoid local optima, better convergence rate. This motivated to apply antlion optimization to solve data gathering tour problem to find the optimal tour with tour distance.

The objective of this work is to find an optimal route for the mobile sink to travel within the deployed network and collect the data from all the sensors. In this paper, a Discrete Ant Lion Optimization (DALO) algorithm is proposed to minimize the mobile sink's tour length of the proposed data gathering tour problem. First the mathematical formulation of the data gathering tour problem was done followed by the basics of Antlion optimization algorithm. Next the proposed Discrete Ant Lion Optimization algorithm is illustrated followed by the performance analysis and conclusion.

Problem Formulation: The Travelling Salesman Problem (TSP) is one among the popular optimization problem dealt extensively in many fields of engineering. The TSP can be stated as follows: Given a set of cities and the distance between each pair of cities, a salesman has to start from a city and find an optimal route visiting all the cities only once and returning back to the starting city that minimizes the travel distance. It is a Non-deterministic Polynomial time complete (NP-Hard) problem which finds itself in various real-world applications, such as transportation, logistics, Genome sequencing, vehicle routing, data gathering, SONET rings etc. [14,15].

In this paper, the data gathering tour problem in WSN is framed similarly to a symmetric Euclidean TSP. Here, each sensor node is assumed as a city in the traditional TSP problem. The mobile sink has to visit all the sensor nodes in the network visiting each sensor node only once minimizing the total travel distance. The mathematical formulation of the data gathering tour problem in WSN as an Integer Linear Programming to find the shortest tour to visit all nodes is as follows [14,15]:

$$min\sum_{x=1}^{n_N}\sum_{y\neq x, y=1}^{n_N} d_{xy}s_{xy} \quad (1)$$

$$0 \leq s_{xy} \leq 1 \quad where \quad x,y=1,...,n_N \quad (2)$$

$$u_x \in Z \quad where \quad x=1,...,n_N \quad (3)$$

$$\sum_{x=1,x\neq y}^{n_N} s_{xy}=1 \quad where \quad y=1,...,n_N \quad (4)$$

$$\sum_{y=1,y\neq x}^{n_N} s_{xy}=1 \quad where \quad x=1,...,n_N \quad (5)$$

$$u_x-u_y+n_N s_{xy} \leq n_N-1 \quad where \quad 1\leq x \neq y \leq n_N \quad (6)$$

where d_{xy} refers to the distance between a sensor 'x' and sensor 'y' and s_{xy} is equal to 1 if there exists a path from sensor 'x' to sensor 'y'. The sensor nodes are labeled with the numbers 1 to n_N i.e for $x,y = [1,2,\ldots,n_N-1,n_N]$, let u_x and u_y be dummy variables. Equation 4 and equation 5 requires that the mobile sink has to arrive at each sensor node from exactly one other sensor node and from each sensor there is exactly one departure to one other sensor respectively. Equation 6 requires that for the mobile sink there is only a single tour covering all sensors and in this modeling, the following assumptions are made. 1) Every feasible solution contains only one closed sequence of sensors 2) For every single tour covering all sensors, there are values for the dummy variables u_x and u_y that satisfy the constraints 3) All the sensor nodes are equally important, contributing to the application with their event details 4) The distance between two sensors from either side is assumed to be equal.

Ant Lion Optimization Algorithm: Ant Lions are commonly called as doodlebug during their larval stages and belong to the family Myrmeleontidae. They are commonly found throughout the regions of the world where it has a warm climate and sandy soil. They are more popular for their funnel-shaped pits produced in the sand during their larval stages to trap ants into it. The Ant Lions predominantly hunt during their larvae stage and reproduce during their adulthood. For hunting its prey the Ant Lions dig a circular pit ranging from 1-3 inches long creating spiral shaped trails in the sand and they wait at the bottom of the pit for an ant or tiny insects to fall into it. When the ant lion identifies a prey in its trap it throws the sand towards the outer edge of its trap to catch the prey with its jaw and pulls it under the soil and consumes it. The ant lions modify its pit after consuming its prey to get ready for its next hunt. The hunting behavior of ant lions motivates the researchers to mathematically model it and apply for numerous optimization problems.

Mirjalili proposed a nature-inspired heuristic algorithm “Ant Lion Optimizer (ALO)” algorithm based on the ant lions hunting behavior and tested it with 19 mathematical functions and three classical engineering problems. It is proved that the ALO algorithm provides a better exploration of the search space, avoiding local optima problem and better convergence rate for continuous optimization problems [16]. The flow diagram of the ALO is given in figure 2. The most important operations in the ALO algorithm are explained as follows:

Random Walk of Ants: In general, ants move randomly searching their food. Here random walk is used to model their movements using cumulative sum function and a random function applied over different iterations. Minmax normalization is used to keep the ants random walks inside the search space while updating their position with respect to selected Ant Lion. The random walk of ants is modeled using equation (7).

$$A(i)=[0,cumsum(2r(i_1)-1);cumsum(2r(i_2)-1);\ldots\ldots;\ldots;cumsum(2r(i_{iter})-1)] \quad (7)$$

where ‘iter’ refers to the number of iterations, i indicates the step size and r(i) is a random function takes the value ‘1’ if the random number generated is greater than 0.5 else it is assigned ‘0’.
Minmax normalization can be done equation (8):

$$A_i^t = \frac{(A_i^t - a_i)\cdot(A_i - c_i^t)}{(b_i^t - a_i)} + c_i \quad (8)$$

where a_i and b_i are the minimum and maximum of the random walk of i[th] variable respectively, c_i^t and c_i^t indicate the minimum and maximum of i[th] variable at t[th] iteration respectively.

Building Traps: A roulette wheel is used to model the Ant Lions hunting behavior. Here it is assumed that the ants will be trapped in any one of the randomly selected Ant Lion. The roulette wheel is used to select an Ant Lion from its population based on their calculated fitness value and this will make a highly fit Ant Lion to catch the ants with high probability.

Entrapment of Ants in Traps: The Ant Lions are able to build their traps proportional to their fitness value and they shoot the sand outside the center of the pit when they find that the ant is inside its trap. This will make the ant slide down when it tries to escape from the Ant Lion.

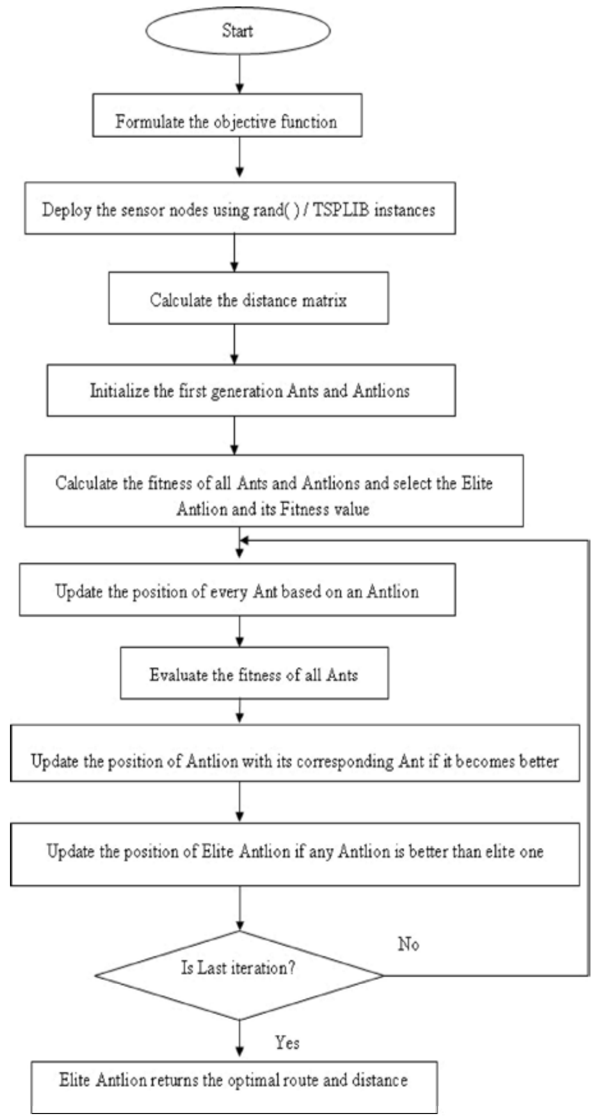

Fig. 2: Flow diagram of DALO algorithm

Catching Preys and Rebuilding Trap: At this stage, when the ant reaches the bottom of the pit, it will be caught by the Antlion. Then the Antlion pulls it in the sand and consumes its body. Next, the Antlion will modify its position and build a new trap to catch a new prey.

It is assumed that the Antlion catches the ant when the fitness of the ant is greater than the fitness of the Antlion

$$Antlion_j^t = Ant_i^t \quad \text{if} \quad f(Ant_i^t) > f(Antlion_j^t)$$

Elitism: This is used to preserve the best solution obtained during each generation and here the fittest ant lion will be named as the elite Antlion and all the ant’s movements are affected during each iteration.

Also, the movements of the ants are also affected by the position of the randomly selected Antlion using a roulette wheel. This will help in achieving the optimal soon quickly across different generations (iterations). This is modeled by the following equation as follows:

$$Ant_i^t = \frac{R_A^t + R_E^t}{2} \tag{9}$$

Where R^t_A and R^t_E is the random walk around the selected Ant lion and elite Ant lion at iteration 't' respectively used to update the position of ith ant.

Discrete Ant Lion Optimization Algorithm: The ALO algorithm initially developed is meant for solving continuous optimization problems and it cannot be applied to solve data gathering tour problem which is a discrete optimization problem. Jati *et al*. [17] proposed a Discrete Firefly Algorithm (DFA) based approach to solve the traveling salesman problem which motivated to propose DALO for the proposed problem. In this paper, a heuristic Discrete Ant Lion Optimization algorithm is proposed to solve the data gathering tour problem to gather from all the sensor nodes in a WSN minimizing the cost of data collection (i.e. Travel distance). Moreover, in the proposed algorithm, it is assumed that the data contained in all sensor nodes are equally important and the Mobile sink has to visit all the nodes in the network and collect their data and forward the same to the base station at the end. This behavior is vitally needed in several sensor network applications.

Solution Representation: In this algorithm, each Antlion and Ant in the initial population represents the initial viable solution to the Data gathering tour problem. Each element in this solution represents a sensor node and the index represents the order of the visit during a tour. The representation of each Antlion and Ant is shown in fig. 3. Here the mobile sink starts its tour from node 3 followed by node 8 and goes as per the order mentioned below and finally visits node 7 and continue the same order for the next round of data collection.

3	8	5	1	10	9	2	4	6	7	→ Node ID
1	2	3	4	5	6	7	8	9	10	→ Index

Fig. 3: Representation of an Ant Lion/Ant

Initial Solution/Population: Here the initial population for Antlions and Ants is generated randomly using randperm ( ) function where each Antlion and ant represent the order to visit the sensor nodes by a mobile sink to collect their data. The pseudo code for initialization phase is as follows:

```
Init_Population = []
for i = 1:SearchAgentsNo
   popu = randperm (No. of sensor nodes)
   Init_Population = concatenate (popu, Init_Population)
end
return Init_Population
```

Fitness Value Computation: In this step, the objective function is evaluated on each initial Ant Lion and ant population. Here Euclidean distance is computed using equation (10) between each pair of the sensor node and labeled as cost matrix. The adjacency matrix is calculated based on the existing path between all the sensor nodes. The Fitness value is calculated using the sum of the product of cost matrix and the adjacency matrix as shown in equation (11). The elite Ant Lion is selected based on the fitness value.

$$Euclidean\ Distance = dist\left(s(1),s(n_N)\right) + \sum_{j=1}^{n_N-1} dist\left(s[j],s[j+1]\right) \tag{10}$$

Fitness value = sum (product (Cost matrix, Adjacency matrix)) (11)

Roulette Wheel Selection: The roulette wheel is used to select a better Antlion using the sorted Antlions fitness value in such a way that the chances are high for that Antlion to catch the ant. The ants walk randomly towards the selected Antlion such that the ant gets entrapped into the pit with high probability leading to the optimal solution (tour length).

Solution Updation: Antlions and ants with higher fitness value are selected after the previous set of operations and made as the new population for the next iteration. The position and the fitness value of the elite Antlion is updated and included as a part of the new population to improve the solution over the various iterations. The above steps are repeated until the numbers of iterations are over or until the optimum solution is obtained.

SIMULATION AND RESULTS

The proposed Discrete Ant Lion Optimization algorithm is implemented using Matlab R2013 running on Core i5 @ 3.1 GHz CPU hosting Windows 7 platform.

The Sensor nodes are deployed randomly using either rand( ) function within a fixed layout or using standard TSPLIB instances.

Table 1: Parameters Settings

Sl.No	Parameters	Values
1	Search agents	40
2	Iterations	100,200,300,400,500
3	Number of nodes	20,40,60,80,100
4	Deployment	random,eil51.tsp, eil76.tsp, eil101.tsp
5	Layout size	250m x 250m
6	Objective function	Cost function

The proposed DALO algorithm is applied to the deployed sensor network within the 250m x 250m layout. The efficient path has been found to visit all sensor nodes by a mobile sink node within the layout and collect their data and report it to the base station at the end. The experiment is repeated 25 times and the average tour length is computed. From fig. 4, it is evident that the DALO algorithm gives an improved tour length compared to ACO and DFA which are popular nature-inspired heuristic algorithms.

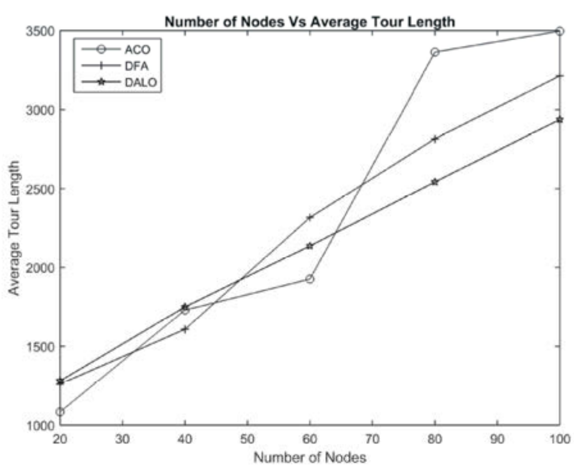

Fig. 4: Number of nodes Vs Tour length (Deployed using rand function Population Size=40, No. of generations=500)

Then the sensor nodes are deployed using instances from standard Traveling Salesman Problem Library (TSPLIB). Here eil51.tsp, eil76.tsp, eil101.tsp from TSPLIB is used to deploy the sensor nodes and the proposed DALO algorithm is applied to find an efficient path to visit all sensor nodes by the mobile sink node across the layout and collect their data. The performance of the proposed algorithm is also compared with the optimum solution (OPT) from TSBLIB. From fig. 5, it is evident that the proposed DALO algorithm gives a reduced tour length compared to ACO and DFA and also attains the near optimal solution.

The proposed DALO algorithm is a nature-inspired heuristic algorithm, whose performance is influenced by the number of generations and elitism. While during the various generations, Elite Ant Lions are selected based on their fitness value and ants are made to update towards the elite Ant Lions making the chance of getting the optimal solution over the iterations. From fig 6, it is evident that the performance of the proposed DALO algorithm is greatly improved by reducing the tour length when compared to ACO and DFA. The results also indicate that over the several iterations, the proposed DALO algorithm converges to the near optimal solution at a high rate compared to other algorithms.

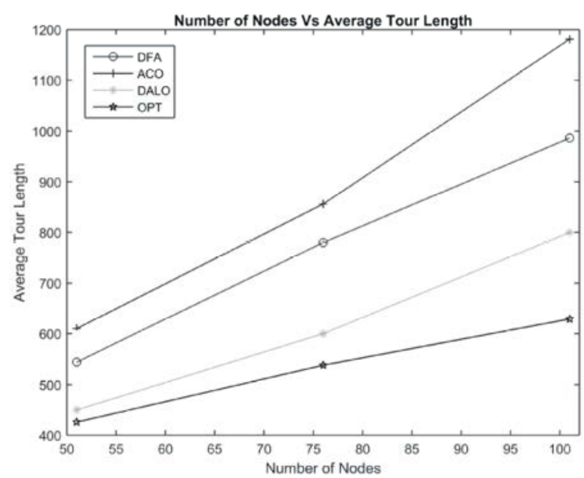

Fig. 5: Number of nodes Vs Tour length (Deployed using TSPLIB instances, Population Size=40, No. of generations=500)

The performance of the proposed algorithm is also evaluated using the accuracy factor for a scenario in which the sensor nodes have been deployed standard TSPLIB instances. Here three standard instances (eil51.tsp, eil76.tsp, eil101.tsp) are considered and the accuracy (A) of the proposed algorithm is evaluated using equation 12. For standard TSP problems, the accuracy of the solution is computed using the ratio of the optimal tour length and tour length calculated by the proposed algorithm. From figure 7 it is observed that the proposed algorithm produces near optimal solution with high accuracy compared to the other algorithms compared here.

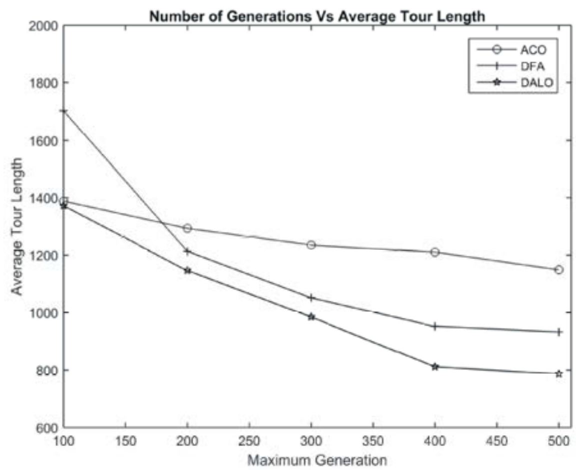

Fig. 6: No. of Generation Vs Tour length (Population Size=40, eil101.tsp, No. of generations=500)

$$A = \frac{Optimal\ tour\ length\ by\ TSPLIB}{Calculated\ Tourlength} \times 100 \quad (12)$$

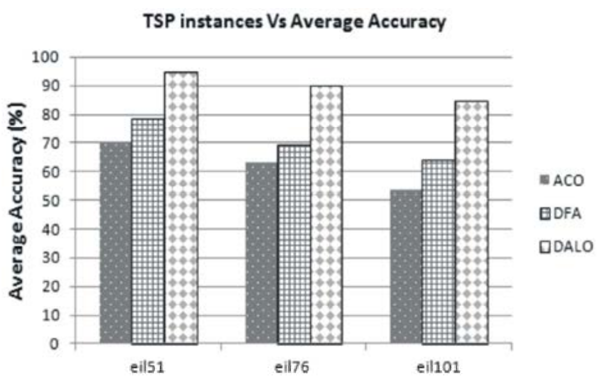

Fig. 7: Performance of DALO algorithm (Population Size=40)

CONCLUSION

In this paper, a Discrete Ant Lion Optimization algorithm is proposed for the data gathering tour problem in wireless sensor networks. The problem is modeled similarly to a symmetric Euclidean TSP problem and the proposed algorithm is applied to the deployed sensor nodes. The proposed algorithm minimizes the total distance traveled by a mobile sink while collecting the data from all the sensor nodes improving the network performance. The algorithm was tested under different conditions and the results demonstrated that the proposed algorithm performs well compared to other approaches in terms of reduced tour length and accuracy of the solution. Further exploration of the various parameters and its impact may be good at achieving the optimal solution with high accuracy. Also, the proposed algorithm may also be applied to scenarios where it involves high data redundancy in a sensor network incorporating data aggregation techniques.

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