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Whale Optimization Approach for Optimization Problem In Distributed Wireless Sensor Network

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ABSTRACT

Recently, Node localization has played a vital role in wireless sensor networks (WSN), where the node's coordinates have mostly required before sensing operation. Sensor devices are randomly deployed in the network for monitoring task. The crucial objective of localization is to determine the position of the sensor nodes based on a few landmark nodes. Node localization problem is formulated as an optimization problem and metaheuristic techniques are called to deal with the issue in multidimensional space, in this paper, the Whale Optimization Algorithm (WOA) is proposed to deal with the challenge, furthermore, the capability of auto localization is highly requested. WOA computes iteratively the node's positions based on a multi-stage approach to browse the whole region of the network. Deploying this algorithm on a large WSN with hundreds of sensors shows good performance in terms of node localization. the simulation result proved the good performance of WOA in term of localization error and computing time .

CCS CONCEPTS

CCS → Networks → Network types → Wireless access networks.

KEYWORDS

Wireless Sensor Network, node localization, optimization problem, metaheuristic, Whale Optimization Algorithm

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1 INTRODUCTION

WSN (Wireless Sensor Network) consists of a large number of densely deployed nodes which are tiny, low power, inexpensive, multi-functional connected by a wireless medium. Its main task is to provide information of environment at each moment, the sensors are installed for tracking and monitoring the environmental requirements and physical phenomenon such as climate prediction, analysis of sane, atmospheric pressure, etc.

WSN is employed in several application domains such as security and surveillance, data aggregation, environment sensing, industrial process control, structural health monitoring [1]. The gathered information needs to be associated with rental sensor nodes to provide an accurate view of the sensor field. Each sensor can monitor its region and proceed to send the collected data to sink node, the effectiveness of WSN is bound to its ability to collect data and transmit them in a minimum time and with greater precision [2]. Numerous challenges are addressed in WSN and have been largely browsed: energy minimization (optimization), energy harvesting, compression schemes, self-organizing network algorithms, routing protocols, security, quality of service management, etc... The three most essential problems are energy efficiency, quality of service and security management [3], moreover, one of the most issues in WSN is node localization, the information location plays a vital role in coverage, deployment purpose, routing information, location service, target tracking, and rescue operations. The intuitive solution is to equip every node with a Global Positioning System (GPS) receiver that can accurately provide the sensors with their exact location, localization by equipping each node with GPS is not suitable, because it is less energy efficient and expensive , it needs large

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size of hardware and has a line of sight problem. On the other hand, If GPS is installed on every node, then it increases the node size and deployment cost. Furthermore, GPS is not energy efficient as it consumes a lot of energy and not suitable for a network like WSN, where for instance, it does not work at all in indoor environments. Numerous localization methods have been proposed for solving the problem, in place of equipping each node by a GPS, the majority of methods allowed to use a certain number of nodes in the network equipped with GPS. These nodes are generally known by anchor nodes, beacons or landmark which their position is known, the remain sensors communicate with the anchor nodes for determinate its positions by using some localization algorithm.

This paper is divided into eight sections, section two gives an survey about localization technique founded, the section three describes the mechanism of Whale Optimization Algorithm, the node localization problem is formulated in section four, In the fifth section a simulation result is presented and analyzed to evaluate the performance of the proposed algorithm, Our conclusion is drawn in the final section.

2 LITERATURE SURVEY

A detailed survey on localization is available in [4-8], furthermore, node localization challenge can be divided via much consideration and according to several criteria: the mobility of the nodes (static vs. mobile, mixed), the execution environment (centralized vs. distributed, mixed), distance estimation (range-free and range-based).

Localization scheme can be divided into three components combined show Fig. 1, where several methods are proposed the first phase (distance estimation). The main task of the first phase is evaluating the distance between beacons nodes and target nodes, where many techniques are used, we found Radio Signal Strength Indicator (RSSI) [9], Time of Arrival (TOA) and Time Difference of Arrival (TDOA) [10], Angle of Arrival (AOA)[11] are applied to calculate the angle or distance [12].

The second phase named position computation, exploiting the data from distance estimation phase it is possible to calculate the coordinates of the target nodes, wherein the several approaches are proposed in this phase: such methods include trilateration multi-lateration, triangulation, probabilistic approaches, bounding box, the central position, fingerprinting [13], there is other work concentrates all information about distances computing that uses mathematical optimization techniques to compute the positions of the nodes.

The third phase of localization scheme is localization algorithm, the combining operation schematized in Fig. 1, localization algorithm determines how the information concerning distances and positions is manipulated in order to allow nodes of a WSN to estimate their positions.

Localization algorithm has received much attention in the last two years, recently, metaheuristic methods have been seen as important tools to solve the problem of optimization, and node

localization is treated as a multidimensional optimization problem, where a substantial number of methods are addressed through population-based stochastic techniques.

PSO (particle swarm optimization) is proposed [14] for node localization problem. After getting the estimated distances and calculated coordinates in the network by the estimation and calculation phases. The basic idea of this approach that all unknown nodes send the coordinates and distance to a base station, the base station runs PSO to minimize the tracking error defined. The approach does not take into account the flip ambiguity problems (Fig. 1), and location of nodes that do not have at least three tags in their neighborhood, The system only works well if either beacon have sufficient range or there is a large number of beacons. In addition, the base station requires estimates the range of all target nodes located in the surrounding of beacons nodes. This requires a lot of communication that can lead to congestion, delays and the depletion of energy. More than, the proposed scheme has limited scalability because the dimensionality PSO is twice the number of target nodes.

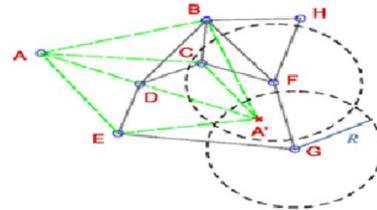


Fig. 1. Flip ambiguity phenomenon

PSO approach BFA are proposed [15] to deal with the localization issue, the distributed architecture is utilized for both approaches, iterative fashion to locate the nodes, this means that each target node that has three or more beacons in its hearing range runs localization Algorithm to minimize the localization error, and each node localized in the iteration i is considered as an anchor nodes at iteration $i+1$.

The process continues iteratively until either all the nodes get localized or no more nodes can be localized, the proposed method does not require that each node transmit its range measurement to a central node. Besides, it can localize all nodes that have three beacons nodes in their range. As the localization iterations pass by, a node may get the number of references for localization, which mitigates the flip ambiguity problem, the situation that results in large localization error when the references are near collinear. However, the proposed method is prone to error accumulation.

A comparison of the performance of PSO and BFA in the number of nodes localized, localization accuracy and computation time is presented according to the results, it has concluded that the two approaches have a trade problem where simulations obtained showed that PSO is convergent quickly by contribution to BFA, on other hand BFA gives many error accuracies than PSO.

Binary PSO is proposed to minimize localization time and energy computing and Improving the original approach, where the same strategy of localization phase utilized in [16], this approach has proven effective in comparison with the original approach,

although it is efficient in terms of convergent but localization error remains low than the original PSO.

h-best PSO is proposed for enhancement of PSO for node localization problem [17], the objective of the proposed approach is to have a fast converging for localization and have a significant localization rate in terms of nodes and minimizing the location error, the results obtained demonstrated that the proposed approach is efficient when compared with PSO original and BBO, Although The HPSO-based localization algorithm determined the accurate coordinates Quickly, whereas BBO-based localization algorithm find the coordinate of the nodes more accurately. The proposed algorithms also reduce the number of transmissions to the base station, that helps the node to retain more energy, and so, the node can perform for a long period.

in [18], a comparative study is presented in this paper, and three famous meta-heuristics: PSO, SFLA, FFA are proposed for node localization in distributed scheme range based, several parameters are combined in comparison as execution time, localization error, number of the non-localized node. For understanding the performance of the proposed algorithms, Lab VIEW platform is used. The obtained results show that the PSO converge rapidly then FFA and SFLA algorithms but it gives more average error then the two other. The point common is that there is not the grand difference in the errors offered by both, the selection of the algorithms to use for localization depends entirely on the hardware available to the user and the time constraints involved. The using of short transmission radius is not suitable for these algorithms.

In 2017, a comparative study is introduced between the three most popular metaheuristic (Bat Algorithm, PSO and DE) in [19], whereas two criteria parameter are evaluated: localization error and localization time), the obtained result shown that Bat algorithm gives more efficiency and accuracy rate is better than the two other.

In 2018, an Effective Bat algorithm is proposed for node localization issues [20], the drawback of original Bat algorithm is improved by introducing the Doppler effect phenomena, The updating frequency makes the algorithm converge rapidly during the moving of the bats and localization error is minimized, on the other hand, two parameters are added to balancing the algorithm and regularize the performance. The simulation results demonstrate that the proposed algorithm has a high convergence rate and greater precision than the original Bat algorithm and particle swarm optimization (PSO) algorithms.

In 2017 , Grey Wolf Optimization (GWO) is another metaheuristic proposed for node localization challenge [21], the simulations results are compared with MBA (modified Bat algorithm and PSO) , we can conclude that GWO is more efficient than the two other proposed algorithm , GWO proved that has faster convergence rate and estimating the location of the node .

Moth Flame Optimization Algorithm (MFOA) is the latest approach proposed to deal with node localization in distributed paradigm of WSN [22], MFOA it is show are combination

between PSO and genetic algorithm (GA) , furthermore, the moth fly smartly through several trajectory as spiral trajectory, the simulations result prove that MFOA is very efficient and improve the performance of the network .

3 WHALE OPTIMIZATION ALGORITHM

The Whale Optimization Algorithm (WOA) was proposed by the authors of Mirjalili and Lewis [23] inspired from the behavior of the humpback whales, the fundamental steps of WOA are summarized as follow :

3.1 Encircling prey

Humpback whales can recognize the location of prey and encircle them. Since the position of the optimum design in the search space is not known a priori, the WOA algorithm assumes that the current best candidate solution is the target prey or is close to the optimum. After the best search agent is defined, the other search agents will hence try to update their positions towards the best search agent. This behavior is represented by the folling equations :

$$\vec{D} = \left| \vec{C} \cdot \vec{X}^*(t) - \vec{X}(t) \right| \quad (1)$$

$$\vec{X}(t+1) = \vec{X}^*(t) - \vec{A} \cdot \vec{D} \quad (2)$$

Where t indicates the current iteration, \vec{A} and \vec{C} are coefficient vectors, \vec{X}^* is the position vector of the best solution obtained so far, \vec{X} is the position vector .

$| \cdot |$ Is the absolute value, and \cdot is an element-by-element multiplication. It is worth mentioning here that X^* should be updated in each iteration if there is a better solution.

The vectors \vec{A} and \vec{C} are calculates as follows :

$$\vec{A} = 2\vec{a} \cdot \vec{r} - \vec{a} \quad (3)$$

$$\vec{C} = 2 \cdot \vec{r} \quad (4)$$

Where \vec{a} are linearly decreased from 2 to 0 over the course of iterations (in both exploration and exploitation phases) and \vec{r} is a random vector in [0,1] .

3.2 Bubble-net attacking method (exploitation phase)

In order to mathematically model the bubble-net behaviour of humpback whales, two approaches are designed as follows :

1. Shrinking encircling mechanism: This behaviour is achieved by decreasing the value of \vec{a} in the equation (3). Note that

the fluctuation range of \vec{A} is also decreased by \vec{a} .

In other words \vec{A} is a random value in the interval $[-a, a]$ where a is decreased from 2 to 0 over the course of iterations.

Setting random values for \vec{A} in $[-1, 1]$, the new position of a search agent can be defined anywhere in between the original position of the agent and the position of the current best agent.

2. Spiral updating position: The spiral equation between the position of the prey and the whale to imitate the helix-shaped movement of the humpback whales is as follows:

$$\vec{X}(t+1) = \vec{D}' \cdot e^{bl} \cdot \cos(2\pi l) + \vec{X}^*(t) \quad (5)$$

It is worth noticing that humpback whales swim around the prey within a shrinking circle and along a spiral-shaped path simultaneously. So in order to model this behavior, we assume the probability of 50% to choose between either the shrinking encircling method or the spiral model, to update the position of whales. The mathematical model is described as follows:

$$\vec{X}(t+1) = \begin{cases} \vec{X}^*(t) - \vec{A} \cdot \vec{D}' & \text{if } p \leq 0.5 \\ \vec{D}' \cdot e^{bl} \cdot \cos(2\pi l) + \vec{X}^*(t) & \text{if } p \geq 0.5 \end{cases} \quad (6)$$

Where $\vec{D}' = \left| \vec{X}^*(t) - \vec{X}(t) \right|$ and indicates the distance of

the i th whale from the prey (best solution obtained so far), b is a constant for defining the shape of the logarithmic spiral, and t is a random number in $[-1, 1]$.

3.3 Search for prey (exploration phase)

The variation of \vec{C} vector can be utilized to search for prey, i.e., exploration phase. Therefore, \vec{C} can be used with the random values greater than 1 or less than -1 to force search agents to move away from a reference whale. The mathematical model for this phase is as follows:

$$\vec{D} = \left| \vec{C} \cdot \vec{X}_{rand} - \vec{X} \right| \quad (7)$$

$$\vec{X}(t+1) = \left| \vec{X}_{rand} - \vec{A} \cdot \vec{D} \right| \quad (8),$$

Where \vec{X}_{rand} is a random position vector (a random whale) chosen from the current population.

3.4 Pseudo code of the WOA algorithm

```

Input data, Number of maxiter and Population etc
Initialize the whales population Xi (i = 1, 2, ..., n)
Initialize a, A, C, l and p
Calculate the fitness of each search agent
X* = the best search agent
while (it < Maxiter)
    for each search agent
        if (p < 0.5)
            if (|A| < 1)
                Update the position of the current search agent by the
                equation (1)
            else if (|A| ≥ 1)
                Select a random search agent (X_rand)
                Update the position of the current search agent by
                the equation (8)
            end
            else if (p ≥ 0.5)
                Update the position of the current search by the by
                the equation (5)
            end
        end
    Calculate the fitness of each search agent
    Update X* if there is a better solution
    it = it + 1
    Update a, A, C, l and p
end while
return X*
    
```

4 NODE LOCALIZATION BASED ON WOA

The main objective of localization is to find out the coordinate of target nodes by using anchor nodes with single hop range-based distributed technique. The main steps of node localization scheme are:

1. M target nodes and N anchor nodes are randomly deployed in the sensor field. Each target node and anchor node has transmission range R . Anchor nodes compute their location awareness and transmit their coordinates. The nodes which get settled at the end of iteration serve as reference nodes during the next iteration and behave like anchors.
2. The node that falls within transmission range of three or more anchors is considered as localized node.
3. Each localized node measures its distance from each of its neighboring anchors. The distance measurements are corrupted with Gaussian noise n_i , due to environment consideration. A node estimates its distance from i th anchor as $\hat{d}_i = [d_i + n_i]$, where d is actual distance given by:

$$d_i = \sqrt{(x - x_i)^2 + (y - y_i)^2} \quad (9)$$

Whereas (x, y) is the location of the target node and (x_i, y_i) is the location of the i th anchor node in the neighborhood

4. Each localizable node WOA independently to localize itself by finding its coordinates (x, y) . The objective function (mean of square of error between actual and estimated distances of computed node coordinates and the actual node coordinates), is minimized by:

$$f(x, y) = \frac{1}{N} \sum_{i=1}^N \sqrt{(x - x_i)^2 + (y - y_i)^2} - \hat{d}_i \quad (10)$$

Where $N \geq 3$ (2 D location of a node needs minimum 3 anchors) is the number of anchors with in transmission range, R , of the target node .

5. Evolves the optimal location of target nodes, i.e. (x, y) by minimizing the error function
6. After coordinate so fall localizable nodes (say, ML) are determined, the mean localization error is computed as the mean of square of distance so of computed nodes coordinates (x_i, y_i) and the actual node coordinates (X_i, Y_i) , for $i = 1, 2$, ML determined for WOA , as shown below:

$$E_L = \frac{1}{M} \sum_{i=1}^L \sqrt{(x - X_i)^2 + (y - Y_i)^2} \quad (11)$$

Where “ $L=M-N$ ”

7. Steps 2 to 6 are repeated by number of iteration defined or until all target nodes get localized or no more nodes can be localized. The performance of the localization algorithm is based on EL and MML , where $MML = [M - ML]$ is the number of nodes that could not be localized. Lesser the value of ML and L , better the performance is.

As the iterations progress, the number of localized nodes increases. This increases the number of references available for already localized nodes. A node that localizes using just three references in an iteration k may have more references in iteration $k + 1$. This decreases the probability of the flip ambiguity.

Algorithm 1 : Multi-stage localization using WOA

- 1: Initialize network topology
- 2: Find unknown nodes with three or more anchor nodes in their neighborhood
- 3: Run WOA algorithm to find location of unknown nodes identified in step 2
- 4: Add localized sensor nodes In current stage to the anchor node list and remove them from unknown node list
- 5: Repeat steps 2-4 until all sensor nodes are localized

5 SIMULATION EXPERIMENTS AND PERFORMANCE EVALUATION

5.1 Simulation Setup

In this subsection, all the simulations are performed using MATLAB 8.4 environment on a laptop of 4 GB memory and i5-2.4 GHz CPU to evaluate the performance of WOA. In our simulation experiments, the sensor nodes are randomly deployed over a 100. 100 square area (see Fig. 2). The number of sensors nodes is 200 and 20 anchor nodes are taken. The transmission range of sensor node is 30. The initial deployment of sensor node is random, so, for each iteration, the number of localizable nodes is not expected to be the same. The unknown nodes coordinates is calculated using WOA.

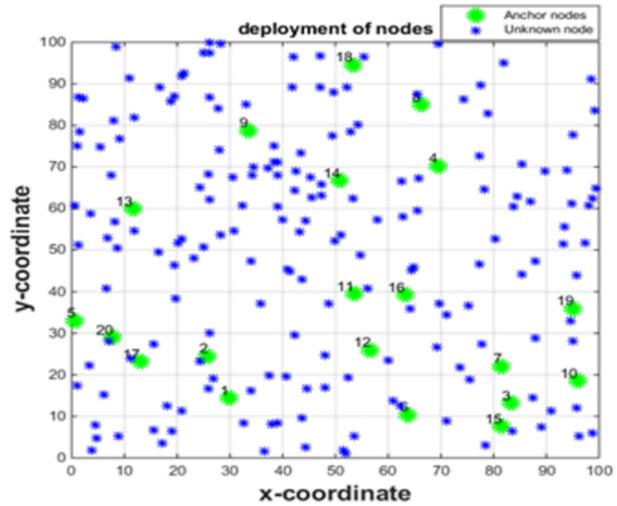


Fig. 2. Nodes deployment in network

The neighbor relationship diagram according to the node deployment is displayed in Fig. 3, The neighbor relationship diagram explains the audience and the relation between the sensors nodes.

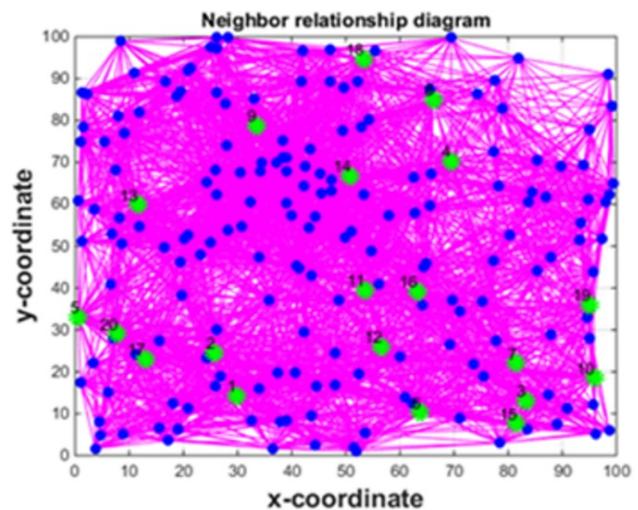


Fig. 3. Communication connectivity of Sensor nodes

The localized and target sensor locations obtained by WOA algorithm are shown in the Fig. 4.

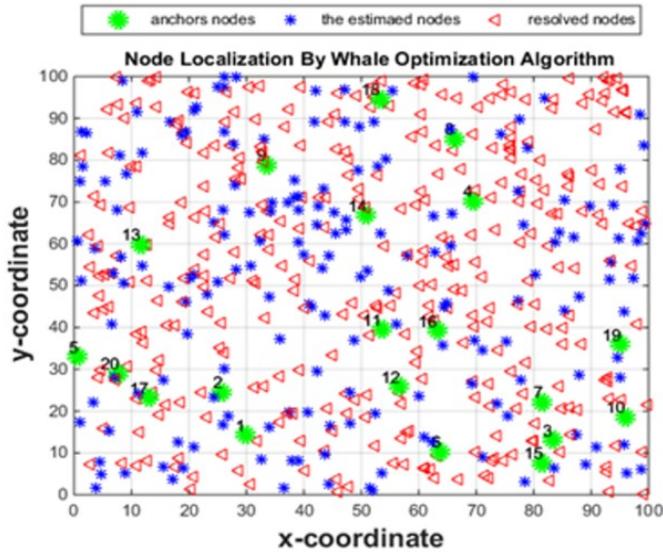


Fig. 4. Node localization By WOA

5.2 Performance Evaluation

In this part, we study the performance of the proposed approach, the convergence time is evaluated with increasing number of iterations. The result of convergence is shown in Fig. 5

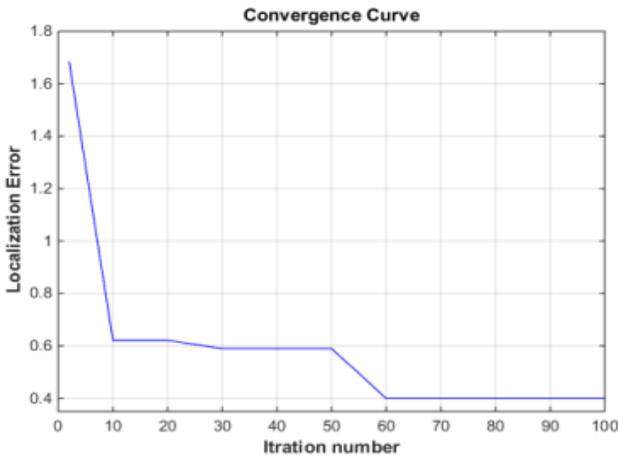


Fig. 5. Convergence of WOA

5.3 Comparative study

In this part, to evaluate the performance of the WOA applied to node localization challenge, a comparative study localization error/localization time versus iteration number is carried out with the most recent metaheuristics: PSO, DE, GWO and MFOA. One hundred sensors nodes are deployed randomly in 100 x 100 m area, the anchors nodes are 4 placed in the corner of the rectangle network to avoid the collinear problem like the literature

[24]. Their coordinates are (0, 0), (0, 100), (100, 0) and (100, 100). In addition, it is assumed that the communication range of the anchors nodes and the sensors nodes in the sensor area and each sensor node can communicate with every other sensor node in the sensor field. The simulation result are presented in the Fig. 6 and the Fig. 7,

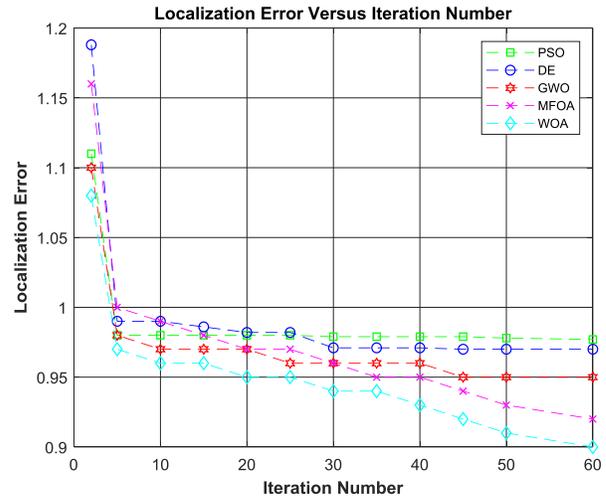


Fig. 6. Localization error versus Iteration number

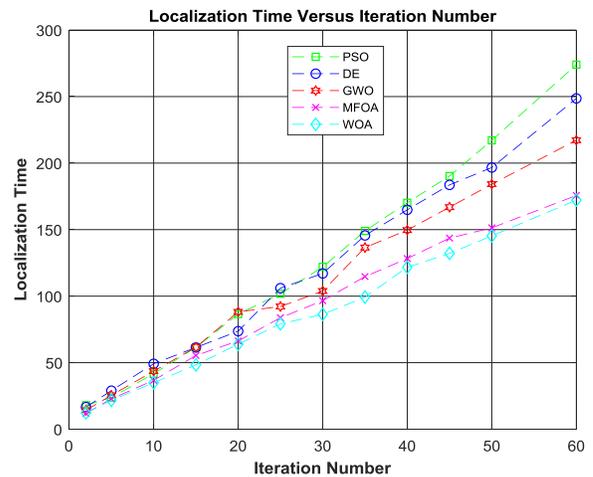


Fig. 7. Localization time versus Iteration number

6 CONCLUSION

Node localization is become very important issues with the evolution technology of internet of thing for network management and topology control. In this paper a recent metaheuristic is proposed to deal with the coordinates of the unknown nodes in square random network, implementing whale optimization algorithm for best localization in wireless sensor networks. The WOA algorithm is very efficient in the both phases exploration

and exploitation, the convergence rate is very remarkable. The proposed algorithm is implemented in distributed paradigm, based in communication range calculated by RSSI estimation distance and Multilateration approach for position computation. So without any additional hardware requirement for location estimation, the cost and energy requirement of the WSN is reduced. In addition, multi stage technique is implemented for improving the performance of the algorithm. And so the reliability and maximization the lifetime of network is increased.

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