New path trajectory followed by Single Anchor by using Salp Swarm Algorithm in Wireless Sensor Network

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Abstract. In the various applications of wireless sensor networks (WSN), the event occurrence information or data sensed by the sensor node has no significance until the location of an event/sensor node is not known. Therefore, localization is an important parameter in WSN for tracking these deployed sensor nodes in the sensing area. To localize these sensor nodes, there are various existing localization models in available detailed literature. One solution to this problem is to deploy a set of static anchor nodes (GPS equipped) in the sensing area, that broadcast their coordination information to help unknown nodes to localize themselves. Another way is to use a single mobile anchor node that will follow a specific path and localize unknown nodes. But a mobile anchor node must follow an optimal path that helps to achieve high accuracy and able to localize a large number of unknown nodes in less computational time. In this paper, the author design and developed a localization algorithm in which a GPS equipped single mobile anchor node follows a new path trajectory i.e. spiral pentagon. Once the target node falls under the communication diameter of the virtual node, six virtual anchor nodes are projected in the shape of a ring around the anchor node and localize all the unknown nodes in the sensing area by using the application of Salp Swarm Algorithm (SSA) for optimization. The hypothesis of six virtual anchor nodes is to avoid the problem of Line of Sight. This proposed method assured that each target node can estimate their node coordinates at least once with a low localization error.

Keywords: Wireless sensor network, Trajectory, Salp Swarm Algorithm, Anchor nodes, Unknown nodes

1. Introduction

Nowadays, The attention of all researchers is captured by WSN due to its great impact on our environment. The characteristics of WSN like self-organization, fault tolerance, and rapid development make them enough promising for various applications like military, tracking, indoor climate control, medical, agriculture, etc. [1-3]. WSN consists of a huge amount of sensing nodes either homogeneous or heterogeneous that are interconnected in-network wirelessly in order to monitor their surroundings. The objective function of these sensing nodes is to collect data from its surrounding environment and forward it to the base station by using either single-hop or multiple hop communication [4-5]. It is necessary to know the location where the information has been collected otherwise there is no use of collected information. To evaluate the exact location of sensor nodes is such a complicated task and this task is known as the problem of localization [6]. In a network, two types of nodes are available where one is anchor nodes that are equipped with GPS having prior information of their coordinates and the other are target nodes whose location coordinates can be
evaluated with the help of anchor nodes. In a fully static environment, the number of anchor nodes should be 10% of the entire network so that all target nodes are able to localize.

In WSN, the node localization method is of two types i.e. range-based and range-free method. Basically, in range-based, the distance/angle information among anchor and target nodes is evaluated with special costly hardware and estimates the coordinates of target nodes and provides the correct information. The available range-based node localization methods are RSSI (Received signal strength indicator), TOA (time of arrival), (TDOA), and AOA (angle of arrival). On the other hand, in range-free distance can be estimated by using hop count among neighboring nodes. The available range-free node localization methods are MDS (Multi-Dimensional Scaling), (APS) Ad hoc positioning system, (DV-Hop) Distance Vector Hop. Because of more feasible and less costly range-free methods are in use more than range-based methods but range-based node localization provides more accurate results though interrupted by noise [7-8].

The author used a range-based localization method and the primary focus of this paper is to follow an optimal path trajectory by traversing pre-defined locations in the sensing area only once i.e in the shape of Spiral Pentagon Trajectory (SPT). SPT having low path length and able to localize all deployed sensor nodes at least once by using Salp Swarm Algorithm (SSA).

The proposed path planning includes the following benefits:

- Instead of using 10% anchor nodes, use a single mobile anchor node that follows a specific predefined path in order to cover the entire network.
- The proposed method takes to guarantee that all the target nodes will able to localized at least once.
- It will reduce the power consumption and cost of the system. Because a single anchor node is used to localize, therefore the lifetime of the network will be increased. This method achieves high localization accuracy in all types of sensing networks.
- If the number of target nodes increases, then there is no need to increase the number of anchor nodes. That single anchor node is able to localize the entire sensing network.
- SSA has not been used before with this path trajectory.

The layout of the remaining paper is organized as given below: section 2. is a detailed investigation of existing localization methods. Section 3. describes the spiral pentagon trajectory. Section 4. explains the optimization algorithm with a theoretical model. Section 5 contains simulation results of the proposed work followed by section 6 includes the conclusion of the proposed work.

2. Related work
To determine the optimal path for a mobile anchor in the sensing area is such a challenging task because the localization error (Difference among evaluated coordinates and actual node coordinates) of target nodes is directly affected by the position of anchor nodes and various researchers provides various path trajectories in literature. During localization, the two primary parameters need to keep in mind: The localization error and the energy consumed by the anchor node should be minimum. Koutsonikolas et al. [9] studied three various trajectories termed as SCAN, DOUBLE SCAN, and HILBERT and described the benefits of these trajectories instead of using any random path. In SCAN, the anchor node either moving towards the x-axis or y-axis. As anchor nodes can broadcast messages only in one direction, therefore, unknown nodes of that direction can localize. To prevent this problem in DOUBLE SCAN, the anchor node first moves towards the x-axis and later towards the y-axis. But it increases the path length followed by anchor. In HILBERT, the first sensing filed is divided into small equal squares and the anchor node follows Hilbert path having a small path length than DOUBLE SCAN and large localization accuracy than SCAN. To prevent the problem of collinearity and path length, Huang et al. [10] proposed two new specific path trajectories CIRCLES.
and S-CURVES. CIRCLE contains several concentric circles so that anchor nodes are able to traverse the entire sensing area and able to localize nodes but the problem is circles are not able to cover the corners of the sensing field efficiently. S-curve is similar to Scan, instead of moving in a straight line, the anchor node makes a ‘s’ curve as the chances of the problem of collinearity in a straight line are high. Hu et al. [11] have been proposed a range-based MACL model where a single mobile anchor traversing the sensing area by moving in the spiral trajectory to prevent the problem of collinearity and periodically broadcast its coordinates information. As spiral trajectory not able to cover corners therefore, nodes placed at corners have high localization errors. Singh P et al. [12] have invented a range-based node localization algorithm in which one mobile anchor node follows the Hilbert path trajectory to locate the unknown nodes in the sensing area to reduce the collinearity problem. When unknown nodes come under the communication range of moving anchor nodes, the distance among them is evaluated and in the shape of a circle at an angle of 60 degrees at the same distance six virtual anchor nodes projected. Han et al. [13] proposed a path trajectory (LMAT) based on an equilateral triangle in which three anchor nodes follow the boundary of the triangle to traverse the sensing area. As the author revealed that localization error is minimum when three anchor nodes form a triangle. For distributed and range-based localization Singh P et al. [13] invented a localization method in which two anchor nodes are deployed at the border of the sensing area and moves parallelly to each other to achieve high localization accuracy and to localize a large number of randomly deployed target nodes. when target nodes falls under the communication radii of anchor nodes, distance is evaluated among them and two virtual anchor nodes per anchor node projected inside the sensing field. Alomari et al. [14] proposed a new static path planning i.e. H-curves for mobile scenario of anchor node and by comparing the proposed work with existing path planning takes the guarantee that all unknown deployed nodes in the sensing area able to localize with high localization accuracy and low energy consumption. Han et al. [15] designed a new path trajectory MAALRH in which the mobile anchor starts traversing the sensing area from the center and starts moving in a hexagon shape and when reaching back to the starting point, the anchor node moves out one step at a distance resolution. But the path length of MAALRH becomes very large.

3. Spiral pentagon Trajectory

![Figure 1: Sprial Pentagon Trajectory](image)

Suppose a square sensing area of 15 * 15 m² having vertex coordinates (X_{minimum}, Y_{minimum}), (X_{minimum}, Y_{maximum}), (X_{maximum}, Y_{minimum}), and (X_{maximum}, Y_{maximum}) where the sensor nodes are moving freely and
the anchor node starts traversing from center of sensing area as shown in figure 1. and the center of sensing area can be calculated by following equations:

\[ X_0 = \frac{X_{\text{maximum}} - X_{\text{maximum}}}{2} \]  (1)

\[ Y_0 = \frac{Y_{\text{maximum}} - Y_{\text{minimum}}}{2} \]  (2)

The equation of SPT used by the mobile anchor node is given in following equations with the resolution of 20 [11]:

\[ X = X_0 + D \times \cos(\theta + \theta_0) \]  (3)

\[ Y = Y_0 + D \times \sin(\theta + \theta_0) \]  (4)

Where \( D \) is use to adjust moving interval of spiral path. \( \theta \) can be calculated by following equation:

\[ \theta = \text{No. of circles} \times 2\pi \times t \]  (5)

where No. of circles means a number of circular path followed by the mobile anchor node i.e. 3, \( t \) is a number of turns i.e. 20 in this paper and \( \theta_0 \) can be calculated by any one of the following equations:

\[ \theta_0 = \tan^{-1}\left(\frac{X_{\text{maximum}}}{X_{\text{maximum}} - 1}\right) \]  (6)

\[ \theta_0 = \tan^{-1}\left(\frac{X_{\text{minimum}} + 1}{X_{\text{minimum}}}\right) \]  (7)

4. SSA based node localization

![Figure 2: (a)Salp, (b) Salpchain](image)

Dr. Mirjalili et al. [16] inspired by the behavior of sea animal salps and invented SSA. Salps are looking like transparent jellyfish that always move in chains as shown in figure 2.

Salpchain consists of salp leader and the rest are followers. In the N-dimension search area, salp's target is food source \( f \). The position of salps is stored in a two-dimension matrix termed as \( Y \). The location of leader of salpchain is updated by the following equation:
\[
\begin{align*}
\gamma_i^1 &= \begin{cases} 
    f + R_1((ub_i - lb_i)R_2 + lb_i) & R_3 \geq 0 \\
    f - R_1((ub_i - lb_i)R_2 + lb_i) & R_3 < 0
\end{cases}
\end{align*}
\] (8)

Where \( R_1, R_2 \) and \( R_3 \) are random numbers. the value of \( R_2 \) and \( R_3 \) are in interval of \([0,1]\), \( ub \) and \( lb \) are upper bound and lower bound respectively, and the responsibility of \( R_1 \) is to balance exploration and exploitation can be calculated by given equation:

\[
R_1 = 2\exp^{-\frac{4m}{n}}
\] (9)

5. Static path mobility
In static path mobility, path followed by the anchor node is set in advanced that cannot modify after the deployment of sensor nodes in the area. Usually, static paths are based on trilateration method. In this section the author compares various static path on the basis of their path length having number of circular paths=3 as shown in figure 3. The Spiral Pentagon has the minimum path length as compares to others.

(a) Circular Path Length = 101.243 m
(b) Hexagonal Path Length = 97.543 m
(c) Spiral Path Length = 78.901 m
(d) Spiral Pentagon Path length = 75.573 m

Figure 3: Comparison of various trajectories

6. Mathematical Formulation
WSNs contains heterogeneous sensor nodes that are deployed in some such area where human may not able to visit for fixing sensor nodes. In WSNs, The primary objective of node localization is to determine the coordinates of randomly deploy \( N \) unknown target nodes coordinates \((X_T, Y_T)\) by using GPS equipped \( M \) anchor nodes coordinates \((X_A, Y_A)\) in a total number of nodes \( n = N=M \) having
communication radius \( r \) with distance information among anchor, target node and single hop range-based distributed method.

A target node could be localized only then if it falls under the communication radii of three anchor nodes. In this paper, only one mobile anchor node follows twenty position and 50 random target nodes are deployed in the sensing area as shown in and is used to localize nodes of the whole network and the algorithm is explained step by step in this section:

**Figure 4: Spiral Pentagon Trajectory**

The Nodes \( N \) are randomly deployed in a network. Initially, the anchor node is placed at \((7.5,7.5)\) coordinates and following SPT to localize every node at least once as shown in figure 4.

- There are two levels in node localization: Ranging and position estimation level. In Ranging level, anchor broadcast beacon messages that contain information of anchor node coordinates. When nearby target nodes fall under the communication radius of the anchor node, for a particular period target nodes listen to the beacon message and collect the anchor’s RSS information. Based on received signal strength, the distance among the target and anchor node is evaluated by equation 9.

\[
D_i = \sqrt{(X_T - X_A)^2 + (Y_T - Y_A)^2}
\]  

(10)

- The estimated distance is disturbed with some gaussian noise \( N_i \) equation 10.

\[
\hat{D}_i = D_i + N_i
\]

- Once the estimated distance is calculated, at the same distance in the shape of ring six virtual anchor nodes having coordinates \((X_{V1}, Y_{V1}), (X_{V2}, Y_{V2}), (X_{V3}, Y_{V3}), (X_{V4}, Y_{V4}), (X_{V5}, Y_{V5})\) and \((X_{V6}, Y_{V6})\) are projected around the anchor node as shown in figure 5. To evaluate centroid \((X_c, Y_c)\), Out of six virtual anchor nodes, only two virtual anchor nodes and third is anchor node (total three) are used for the Trilateration Method by using the following equation.

\[
(X_c, Y_c) = \left(\frac{X_A + X_{V1} + X_{V2}}{3}, \frac{Y_A + Y_{V1} + Y_{V2}}{3}\right)
\]  

(11)
Figure 5: Deployed six virtual anchor nodes around main anchor node.

The evaluated centroid is considered as an estimated coordinated $(X_e, Y_e)$ of the target nodes.

- Deploy salp particles around evaluated centroid.
- Furthermore, with the aim of high localization accuracy, the algorithm is executed at each target node to estimate its coordinates $(X_s, Y_s)$ in the sensing field. The objective function $(X_s, Y_s)$ is formulated as mean of square of error between estimated distance and actual distance of actual node coordinates $(X_t, Y_t)$ and estimated node coordinates $(X_e, Y_e)$ given by equation 12.

$$f(X_s, Y_s) = \frac{1}{M} \sum_{i=1}^{M} \left[ \sqrt{(X_e - X_i)^2 + (Y_e - Y_i)^2} - D_i \right]^2$$

- Where $M \geq 3$ according to the trilateration method, in 2D environment minimum three anchor nodes are required to calculate centroid. The purpose of objective function is to minimize the localization error.
- Once all target nodes are localized $N_L$, Localization error $E_L$ is computed as the mean of square of distance between the actual node coordinates $(X_t, Y_t)$ and estimated node coordinates $(X_e, Y_e)$ given by equation 13.

$$E_L = \frac{1}{N_L} \sum \sqrt{(X_e - X_t)^2 + (Y_e - Y_t)^2}$$

- The efficiency of algorithm is computed by average localization error $E_L$ and number of non-localized nodes.

$$N_{NL} = N_T - N_L$$

The higher the value of $E_L$ and $N_{NL}$, the lower the efficiency and performance of the algorithm. Repeat steps 1-6 until every unknown node becomes known nodes.

The complete flow diagram of the proposed algorithm is shown in figure 6.
7. Simulation results and Discussions
The WSN localization simulation is done in MATLAB software by utilizing the applications of SSA in a sensing area of 15m*15m where the single mobile anchor node in the SPT with 50 static target nodes as shown in figure 4. The simulation results are executed on the personal computer having Intel Core i5 2.50 GHz processor and of 8 GB of RAM. The strategy used by the author for the application of SSA is explained below. The transmission range could be varied according to the size of the network area. In this paper, the author has been used 15 * 15 SI units$, so the communication range is 5m. For a large number of localized node communication range can be increased or vice versa according to the requirement.

![Figure 6: Flow of localization algorithm](image)
In the scenario of the mobile anchor node, the authors investigated SSA based localization of target nodes. This algorithm is stochastic, therefore for the same deployment, no identical solutions will be available. In this paper, the complete simulation is executed by twenty times starting from anchor position (7.5,7.5) coordinates by traversing the whole network in SPT to the last anchor position (0,4.5) coordinates as shown in figure 4.

The parameters used by SSA are given below:
Population size of salp particles= 20
Gaussian noise =0.1
Maximum number of iterations =100
Random number $R_1$ is calculated by equation (8) and values $R_2$ and $R_3$ are in interval of [0,1]
Transmission range of Anchor and virtual anchor nodes = 5 m

The simulation results of the proposed algorithm are in terms of the localization error, computing time, and the number of localized nodes. On a particular position of anchor node, Max LE is the maximum localization error, Min LE is the minimum localization error and ALE is the average localization error as given in table 2. Localized nodes means the number of nodes in the communication radius of anchor nodes at a particular position having their estimated coordinates.

The computational time of the localization algorithm should be less i.e in less computing time the algorithm should localize the maximum number of nodes. Figure 7. shows the specific sixteen positions of anchor nodes, the computational time for SSA. With the purpose of less computing time, only 100 iterations are used. To increase localization accuracy, the number of iterations can be increased according to a cost function. The average computing time for SSA is 0.4301 seconds.

In literature, there are many localization algorithms available for the static scenario but in the case of a mobile scenario, very less work is done and SSA has not been used before for this trajectory.

![Figure 7: Computing time for all twenty positions followed by the anchor node.](image)

In the networking area, the target nodes are randomly deployed and one anchor node follows a specific path i.e. SPT in this paper. The simulation results of each anchor position are shown in figure 8 where the blue diamonds show the actual target positions and red plus shows the estimated position of nodes. The red circle in the center is the anchor node surrounded by six virtual anchor nodes in the shape of the ring. The result of the first position and last position is given in figure 8.
Figure 8: 1st Position and 20th Position of anchor node
Table 2: Simulation summary of SSA for all twenty positions followed by anchor node.

|    | Anchor coordinates | Max LE | Min LE | ALE | Localized nodes |
|----|--------------------|--------|--------|-----|-----------------|
| SSA | 7.50               | 0.5532 | 0.0927 | 0.2455 | 20              |
| SSA | 7.42               | 0.5413 | 0.0343 | 0.2337 | 17              |
| SSA | 8.11               | 0.5194 | 0.0294 | 0.2587 | 18              |
| SSA | 8.75               | 0.4678 | 0.0192 | 0.2512 | 19              |
| SSA | 8.10               | 0.4807 | 0.0547 | 0.2608 | 18              |
| SSA | 6.25               | 0.448  | 0.0932 | 0.257  | 17              |
| SSA | 4.95               | 0.5278 | 0.0843 | 0.2754 | 18              |
| SSA | 6.00               | 0.4976 | 0.0457 | 0.1987 | 17              |
| SSA | 9.02               | 0.4608 | 0.0623 | 0.2517 | 14              |
| SSA | 11.30              | 0.4681 | 0.0611 | 0.2136 | 14              |
| SSA | 10.22              | 0.4642 | 0.08552| 0.2483 | 16              |
| SSA | 6.13               | 0.3998 | 0.0322 | 0.2833 | 12              |
| SSA | 2.60               | 0.4125 | 0.1362 | 0.2374 | 12              |
| SSA | 3.31               | 0.5236 | 0.0359 | 0.222  | 18              |
| SSA | 8.29               | 0.4432 | 0.0417 | 0.2492 | 11              |
| SSA | 13.25              | 0.3954 | 0.0907 | 0.2179 | 12              |
| SSA | 13.31              | 0.429  | 0.0323 | 0.2398 | 8               |
| SSA | 7.74               | 0.3942 | 0.1001 | 0.2638 | 8               |
| SSA | 1.23               | 0.4825 | 0.1136 | 0.3298 | 6               |
| SSA | 0.00               | 0.4754 | 0.0859 | 0.2774 | 12              |

8. Conclusion
This paper invented a range-based, distributed method where randomly deployed sensor nodes in the sensing area are localized with the help of single mobile anchor nodes. The mobile anchor node follows an optimal new path trajectory i.e spiral Pentagon Trajectory by utilizing the application of SSA. This paper proved that SPT has minimum path length as compares to exiting literature work and SSA has not been used before with this path trajectory. The proposed algorithm can be used for military applications or in a difficult environment like forest and ocean where a human cannot go and fix nodes. The proposed algorithm can be implemented for single-hop/multi-hop range-free localization for a fully mobile scenario. Future work is focused on the hybrid algorithm with different path planning and different optimization algorithm which can be used to gain high accuracy.

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