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Cuckoo Search with Mobile Anchor Positioning (CS-MAP) Algorithm for Error Minimization in Wireless Sensor Networks

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Abstract

In Wireless Sensor Networks (WSNs), one of the most important issues is the localization of the sensor nodes. In general, the location information is useful for coverage, deployment of sensor nodes and rescue operations. Many applications like routing and target tracking are location dependent. The goal of localization is to determine the physical co-ordinates of a group of sensor nodes. Environmental data becomes information when the data is accompanied by the location information (from where the data comes).Hence, this work aims at determining the location of the sensor nodes with high precision. This work is based on localizing the nodes using Mobile Anchor Positioning (MAP), a range-free localization method. As the anchors move through the network, they broadcast their location as beacon packets. The sensor nodes use the location information of beacon packets obtained from mobile anchors as well as the location packets from neighbouring nodes to calculate their location. The proposed algorithm used for Localization is Cuckoo Search with Mobile Anchor Positioning (CS - MAP). We have incorporated CS – MAP algorithm over the results of MAP to enhance the location accuracy. Root Mean Square Error (RMSE) has been used as a performance measure to compare between the two approaches namely, MAP and CS-MAP. Simulation results show that our proposed Cuckoo Search with Mobile Anchor Positioning (CS-MAP) algorithm is effective in bringing down the localization error largely when compared to MAP.

Key words

Localization; Range-free methods; Mobile Anchor ; Cuckoo Search; Root Mean Square Error;

1. Introduction

Wireless Sensor Network (WSN) is a kind of ad hoc network that consists of autonomous sensors with low cost, low energy sensing devices, which are connected by wireless communication links. These sensor nodes are tiny in size and possess limited resources namely processing, storage, sensing and communication [1]. They are usually deployed in large numbers over the region of interest for object monitoring and target tracking applications. The densely deployed sensors are expected to know their spatial coordinates for effective and efficient functioning of WSNs. Location awareness plays an important role in high-level WSN applications like locating an enemy tank in a battlefield and locating a survivor during a natural calamity and in certain low-level network applications like geographic routing and data centric storage.

Localization is a fundamental problem which can be defined as the process of finding the position of the sensor nodes or determination of spatial coordinates of the sensor nodes. Localization is especially important [2] when there is an uncertainty on the exact location of fixed or mobile devices. Localization is the process of making every sensor node in the sensor network to be aware of its geographic position [3]. The usual solution is to equip each sensor with a GPS receiver that can provide the sensor with its exact location. As WSNs normally consist of a large number of sensors, the use of GPS is not a cost-effective solution and also makes the sensor node bulkier [4]. GPS has limited functionality as it works only in open fields and cannot function in underwater or indoor environments. Therefore, WSNs are required of some alternative means of localization.

Currently the existing non-GPS based sensor localization algorithms [5] are classified as range-based or range-free. Range-based localization schemes rely on the use of absolute point-to-point distance or angle estimate between the nodes to determine the position of unknown sensor nodes using some location-aware nodes. Location-aware nodes are also called as anchors or beacons. Typical range-based localization techniques used are Received Signal Strength Indicator (RSSI) [6], Time Difference of Arrival (TDoA) [7], Time of Arrival (ToA) [8], and Angle of Arrival (AoA) [9]. Depending on the signal feature used, the position estimation is found using geometrical approaches such as Triangulation, Trilateration or Multilateration. Range-based methods give fine-grained accuracy but the hardware used for such methods are expensive. In range-based mechanisms, the nodes obtain pair wise distances or angles [10] with the aid of extra hardware providing high localization accuracy. Due to cost, the use of range-based methods will not be preferred.

Range-free or proximity based localization schemes rely on the topological information, e.g., hop count and the connectivity information, rather than range information. Range-free localization schemes may or may not be used with anchors or beacons. A range-free localization scheme does not involve in the use of complex hardware and are cheaper when compared to range-based schemes. Range-free methods use the content of messages from anchor nodes and other nodes to estimate the location of non-anchor sensor nodes. Centroid Algorithm [11] and Distance Vector Hop (DV-Hop) method [12] are certain range-free algorithms. Range-free algorithms sometimes use mobile anchors [13] for localization. Range-free algorithms are not costly but they provide coarse-grained accuracy. Range-free schemes provide lower localization accuracy at lower cost.

Localization in Wireless Sensor Networks is intrinsically an unconstrained optimization problem [14]. Evolutionary algorithms are local search methods, capable of efficiently solving complex constrained or unconstrained optimization problems. The proposed evolutionary approach namely Cuckoo Search with Mobile Anchor Positioning (CS-MAP) algorithm is applied after performing location estimation using mobile anchors. This work uses a range-free approach, where the anchor nodes broadcast their location on the move and the obtained localization result is optimized by means of optimization as stated above.

The rest of the paper illustrates the related research work in this area, elaborates the proposed Cuckoo Search with Mobile Anchor Positioning (CS-MAP) algorithm and compares the performance of proposed evolutionary algorithm with an existing algorithm namely Mobile Anchor Positioning.

2. Related Work

W-H Liao et al. [15] proposed an algorithm (Mobile Anchor Positioning) in which each sensor node receives beacons (messages containing location information) in its receiving range from the moving anchor as the anchor moves around the sensing field. Among the received beacons, the sensor node selects the farthest two beacons. The node constructs two circles with each chosen beacon as centre. The radius of the circle is the communication range of the sensor node. It determines the intersection points of the two circles. Out of the two points, one is chosen to be the location of the sensor node based on a decision strategy.

Kuo-Feng Ssu et al. [16] presented a range-free algorithm, which uses the following conjecture. A perpendicular bisector of a chord passes through the centre of the circle. When there are two chords of the same circle, their perpendicular bisectors will intersect at the centre of the circle. A mobile anchor moves around the sensing field broadcasting beacons. Each sensor node chooses two pairs of beacons and constructs two chords. The sensor node assumes itself as the centre of a circle and determines its location by finding the intersection point of the perpendicular bisectors of the constructed chords.

Baoli Zhang et al. [17] proposed a range-free algorithm, which works as follows. The trajectories of the mobile anchor are in such a way that it moves in a straight line. As it moves, it periodically broadcasts its location to the sensor nodes. A sensor node selects four beacons among all collected beacons. The first group (two beacons) is the location of the mobile anchor node when it first enters the communication range of the sensor node. The second group is the location of the mobile anchor node when it second enters the communication range of the sensor node. After these positions and the communication range are obtained, four circles are constructed with the chosen four points as centres. Four intersection points s_1, s_2, s_3, s_4 of the circles are calculated. Then using the centroid formula on the four intersection points, the position of the sensor node is calculated.

Wenwen Li et al. [18] proposed the Genetic algorithm for localization of the sensor nodes and constructed the solution space, coded the solutions, formulated the fitness function and used appropriate selection mechanism to choose the parents for the next generation. The reproduction operation on the individuals is further performed and the solution is obtained with high accuracy. The above genetic algorithm approach gives good localization accuracy but the solution space is very huge. The algorithm has to search a large number of solutions in each of the iterations or the number of iterations will be large. When the area of the sensing field increases, the computation involved also increases.

The first three approaches have advantages - Like, they do not require additional hardware and depend only on messages passed but they are coarse grained i.e. their accuracy will not be very high.

Gopakumar et al. [19] proposed the swarm intelligence based approach for localization of the sensor nodes for this non-linear optimization problem. The objective function chosen is the mean squared range error of all neighbouring anchor nodes. The PSO algorithm provides better convergence than simulated annealing and ensures solution without being trapped into local minima.

YaoHung Wu et al. [20] proposed a distributed localization approach known as the Rectangle Overlapping Approach (ROA), which uses a moving beacon equipped with a GPS and a directional antenna. The positions can be determined using simple operations according to the current state of the moving beacon, including the rotation angle and position. The node positions can be determined accurately after the beacon operates along straight- line traverse routes.

Jia Huanxiang et al. [21] proposed a new localization method with mobile anchor node and genetic algorithm. It combines weighted centroid method with genetic algorithm. Initially, the mobile anchor node, which is equipped with GPS, was allowed to traverse around the entire sensing area. The unknown sensor nodes can obtain useful information for localization through mobile anchor node. Then, the initial coordinates of unknown sensor nodes are calculated by the weighted centroid method. Now, the initial position coordinates of the unknown sensor nodes are converged towards the actual coordinates. As the genetic algorithm is iterative - looped, the localization accuracy is improved to some extent.

Huan-qing Cui et al. [22] proposed a Weighted Centroid Localization method using three mobile beacons. These beacons preserve a special formation while traversing the network deployment area, and broadcast their positions periodically. The location unaware sensor nodes that are to be localized estimate the distances to these three beacons and use weighted centroid localization method to find its position. Through simulation results, this method was found superior to Weighted Centroid Localization method with a single mobile beacon as well as to Trilateration.

Zhen Hu et al. [23] proposed a Radio-Frequency (RF) based Mobile Anchor Centroid Localization method (MACL) for WSNs. In this method, a mobile anchor node moves in the sensing field and broadcast its current location periodically. Simulations and tests from an indoor deployment using the Cricket location system were used to investigate the localization accuracy of MACL. From the results of RF based MACL, it provides less computational complexity with low communication overhead, low cost, and flexible accuracy.

Lutful Karim et al. [24] proposed a Range-free Energy Efficient Localization Technique using Mobile Anchor (RELMA) especially for large scale WSNs to improve both accuracy and energy efficiency by minimizing the number of anchor nodes used. The RELMA_Method1 as well as RELMA_Method2 have used the sensing range for each pair of nodes to communicate instead of the communication range to reduce the power consumptions of the nodes. The performance of RELMA_Method1 and RELMA_Method2 are compared only with the existing Neighboring-Information-Based Localization System (NBLS). Simulation results demonstrate the fact that RELMA_Method1 and RELMA_Method2 outperform NBLS in terms of localization accuracy as well as energy efficiency.

Xu Lei et al. [25] proposed a Mobile Anchor Assisted Localization Algorithm based on PSO (MAAAL_PSO) pertaining to adverse or dangerous application environments. The Region of Interest (ROI) is divided into grids and the mobile anchor deploys virtual anchors on the vertex of each grid. Based on this deployment, the node localization is converted into non-linear constrained optimization problem solved by PSO with the help of mobile anchor. After a few iterations, Performance evaluations demonstrate that this algorithm improves localization accuracy. It is also robust to the interference of environment noise.

Han Bao et al. [26] proposed a PSO based localization algorithm (PLA) for WSNs with one or more mobile anchors. PLA does not require the mobile anchors to move along an optimized or a pre-determined path. This property makes mobile data sinks with localization capability to serve for data gathering and network management applications. Simulation results demonstrate that PLA can achieve superior performance in various scenarios i.e. in wide range of conditions when compared to centroid localization method.

The range-free approach proposed in this paper is Cuckoo Search with Mobile Anchor Positioning (CS - MAP) Algorithm. Cuckoo optimization algorithm [27] has the advantages of high accuracy with the usage of less hardware. The location of nodes is initially estimated using Mobile Anchor Positioning. Then the proposed evolutionary strategy, Cuckoo Search with Mobile Anchor Positioning (CS - MAP) Algorithm is applied over the results obtained by Mobile Anchor Positioning (MAP). The observation is that, when CS-MAP is applied over the MAP algorithm, it estimated the location of the nodes providing very high accuracy better than MAP.

3. Proposed Localization Approach

The localization strategy used in this work can be visualized to work in two phases. In the first phase, a range-free algorithm namely Mobile Anchor Positioning (MAP) is used for determining the location of the unknown sensor nodes. Since a range-free algorithm is used, (which offers coarse-grained accuracy) the obtained location will be just as an estimate. In the second phase, an evolutionary strategy namely Cuckoo Search with Mobile Anchor Positioning (CS - MAP) algorithm is applied over MAP for fine-tuning the results of the sensor nodes obtained using MAP and helpful to improve localization accuracy.

3.1 Mobile Anchor Positioning (MAP)

The simulation environment is set-up as follows: The sensor nodes are randomly deployed in the sensing field. Mobile anchors are location aware nodes that move in the sensing field, fitted with GPS. As they move around the sensing field, they periodically broadcast messages containing their current location at fixed time interval to all the nodes, which are at a hearing distance from it. Such messages are known as beacons. The mobile anchors traverse around the field with a specific speed and their directions are set to change for every 10 seconds. All the nodes in the communication range of the mobile anchor will receive the beacons. A sensor node will collect all the beacons in its range and store it as a list. Communication range of the sensor node and the mobile anchor node are assumed as same. Once enough beacons are received and if a sensor node does not receive a beacon, which is at a distance greater than the already received ones, the localization begins at that particular node.

Assume that the sensor node has received and stored four beacons (locations of the mobile anchor) in its list {T_1, T_2, T_3, and T4} (refer Fig.1). From the list, two beacons, which are farthest from each other, are chosen (T_1, T_4). These points are known as Beacon points. These two points are marked as the end of the sensor node's communication range since the sensor node has not received a beacon farther from this point. Hence T_1 and T_4 (Beacon points) represent either two positions of the same mobile anchor or positions of two different mobile anchors when they were at the end of the sensor node's communication range.

With these two Beacon points as centres and the communication range of a sensor node as radius, two circles are constructed (refer Fig.1). Each circle represents the communication range of the mobile anchor, which has sent the beacon. The sensor node has to fall inside this communication range, as it has received the beacon. Since the sensor node has received packets either from both anchors or from the two positions of the same anchor, the node has to fall inside both the circles. Hence, it can be concluded that circles will intersect each other.

The intersection points of both circles are determined (S_1, S_2). The intersection points are the possible locations of the sensor node. The reason is as follows: The two farthest points (Beacon points) are the end points of a sensor node's communication range. Therefore, in the circle with the mobile anchor's position as the centre and the communication range of a node as the radius, the sensor node will be in the circumference of the circle.

The sensor node lies on the circumference of the other circle since it is the same with the other mobile anchor position. Therefore, the sensor node lies on the circumference of both the circles. The only points satisfying the above condition are the two intersection points. Hence, by means of Mobile Anchor Positioning, the location of the sensor node has been approximated to two locations.

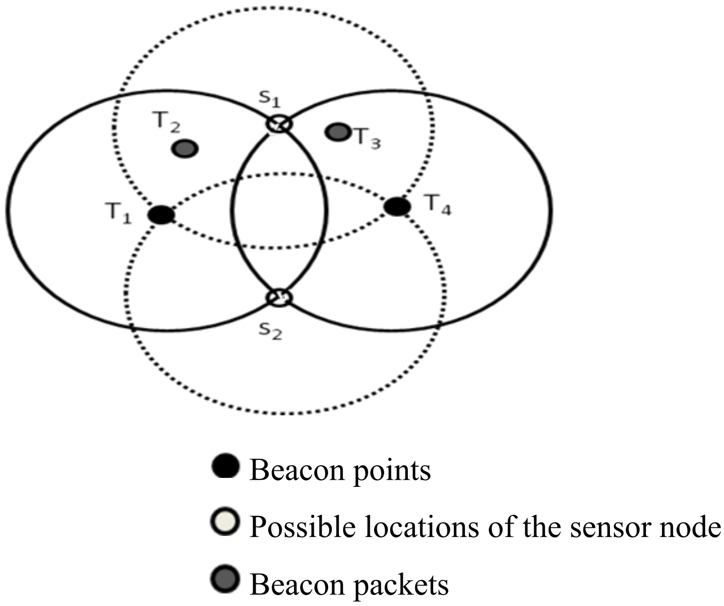


Fig.1. Possible locations of the sensor node.

3.1.1 Identifying the Sensor Locations using MAP-M

The visitor list is searched after identifying the two possible positions i.e. the intersection points. If a node could hear around its range, there is a possibility of a beacon point which can be situated at a distance r from one of the two possible locations. Thus, there is one point in the list, whose distance from one possible location is less than r, and the distance from other possible location is greater than r, then the first possible location is chosen as the location of the sensor node.

It is assumed that the communication range of a mobile anchor is R. The MAP-M maintains the visitors list after receiving the beacon packets from the mobile anchor. The information from the visitor list is used to approximate the location of the sensor node. Let the visitor list of a sensor node S consists of various location information represented as {T1, T2… Tn}. The beacon points are the two extreme points i.e., T1 and Tn. Two circles with radius R and center T1 and Tn are constructed and their intersection points of two circles are found to be S′ and S″.

If there is any Ti ($2 \leq i \leq n-1$), such that the distance between Ti and S′ is less than R and that between Ti and S″ is greater than R, then we can conclude the location of the sensor node is S′. This is because of the fact that the sensor node should lie inside the communication range of mobile anchor to receive the beacon packets. Consequently, the distance between the sensor node S and beacon packet Ti should be less than R.

There is an area named as the shadow region, as shown in Fig 2. If all the Beacon points lie inside this region, it is not possible to determine the location of the sensor as the shadow region comes under the range of both the intersection points. This could be explained by drawing two circles with S' and S" as centre and the shadow region is the intersection of the two circles. Hence, in order to estimate the location of the sensor node there is a need that at least one of the beacon packets in the visitor list must lie outside the shadow region, as shown in Fig.3.

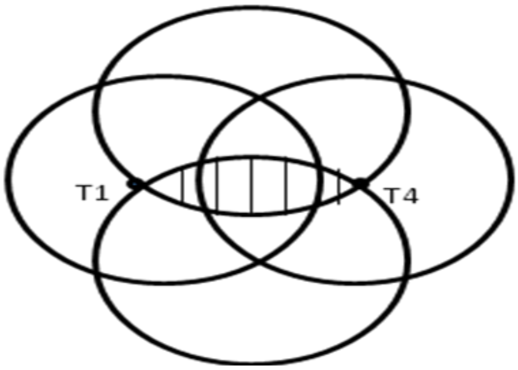
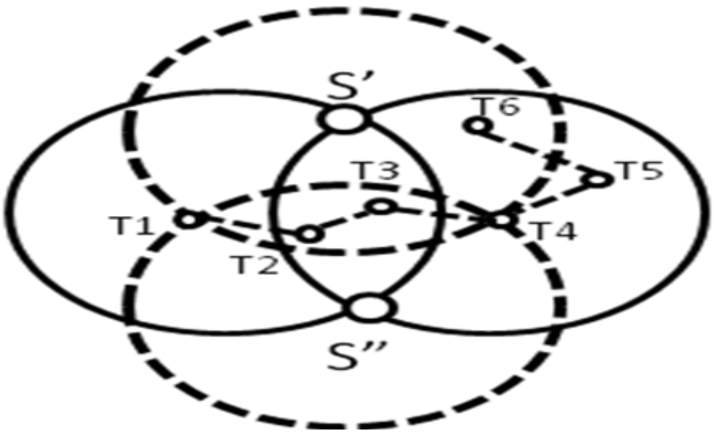


Fig 2. Shadow Area



S' and S'' indicate possible locations of the sensor node

Fig. 3. Node seeking Information from Neighbour Sensors

Therefore, it is not possible to determine the location of the sensor node S using the available beacon packets, thus the node is made to wait until it gets further beacon packets. If no further beacons are obtained, then a single position of sensor node S cannot be obtained. The node will have two positions S' and S". To overcome this problem, the method of Mobile Anchor Positioning-Mobile Anchor & Neighbour (MAP-M&N) is being adopted.

3.1.2 Forming additional Anchors and identifying Sensor Locations with MAP - M&N

The location estimation done for sensors using MAP-M method gives positions for few sensors and for the others, it gives two positions and so it is the responsibility of MAP-M&N method to produce outputs with a single position for each sensor. It is possible for the sensor nodes that have already determined their location to assist other nodes in determining their locations. As soon as the location is identified, the localized nodes start acting like anchors. They embed their calculated location inside the packet and then broadcast the beacons. Nodes, which are at its hearing range and waiting for additional beacons to finalize their location, can make use of these beacons. However, if the sensor node has determined its location, it simply discards the beacon packet. As a consequence, by using MAP-M&N method, the cost of movement of the mobile anchor can be reduced.

The steps involved in finding the location of the sensors in the field using MAP – M & N method are listed below:

1. Deploy 100 sensor nodes randomly in the 1000 m x 1000 m area of the sensing field in the simulation environment and deploy 3 location aware nodes (anchor nodes) i.e sensor nodes fit with GPS.

2. The anchor nodes move randomly through the entire sensing field. The anchor nodes periodically broadcast their location packets, which are known as beacon packets, while on the move through the sensing field.

3. Every sensor node maintains a visitor list containing beacon packets based on the information obtained from anchors.

4. The sensor nodes can identify the farthest beacon packets and chooses those beacon packets as beacon points.

5. With those two beacon points as the centres and the communication range of a sensor node as radius, two circles are constructed and the intersection points are found.

6. Sensor nodes try to identify its position out of the two intersection points. Here, atleast one of the beacon points in the visitor list must lie outside the shadow region or based on the beacon points obtained from neighbour nodes.

7. The approximate location for each of the sensor nodes is estimated using the MAP M & N method.

3.2 Cuckoo Search with Mobile Anchor Positioning (CS - MAP) Algorithm

The algorithm takes the results of Mobile Anchor Positioning (MAP) as its input. The results of MAP-M&N, giving the approximate solution of the location of each sensor at each specified time instance are given as the input to the post optimization method.

1. Let each node's (x,y) co-ordinates at different instances of time be (x1,y1),(x2,y2)......(xn,yn), where n denotes the number of sensor nodes. Each of these positions is considered as separate cuckoo. Hence, producing as much of cuckoos around the approximate positions, which are found at regular intervals.
2. Each cuckoo lays eggs at random positions inside the chosen area around it.
3. A circle of radius 'r' is formulated around the approximate positions to eliminate the other eggs that were laid.

   r = [number of eggs per Cuckoo/sum] * (radiusCoeff * (varHi-varLo) (1)

4. With this, a bunch of possible locations of the sensor node is created. Thereby, it is built in and around the approximate locations obtained from MAP - M&N and it is repeated to narrow down the solution around the area of the approximate solution.
5. At first round, each of the egg's position is compared with the position of all the other eggs and eliminated if the difference is comparatively large and hence ending up in one egg. Thus, the best habitat for this particular round is found.
6. The position of this egg is given as the input to the next round and the process is continued until the stopping criterion meets its profit value.

   Stopping criteria = Maximum iterations or Profit value; Maximum iteration = arbitrarily chosen as 100; Profit value = Minimum difference in values (10cm) obtained in the current and previous rounds.

7. As a result, various cuckoos give different (x,y) coordinates for a single node, hence the average of the obtained positions given by each cuckoo is estimated as the (x,y) coordinate of that particular node.
8. The same procedure is performed for each of the other nodes.

The pictorial representation in Fig.4. below shows how to locate the sensors in the field based on MAP – M & N along with CS-MAP Algorithm.

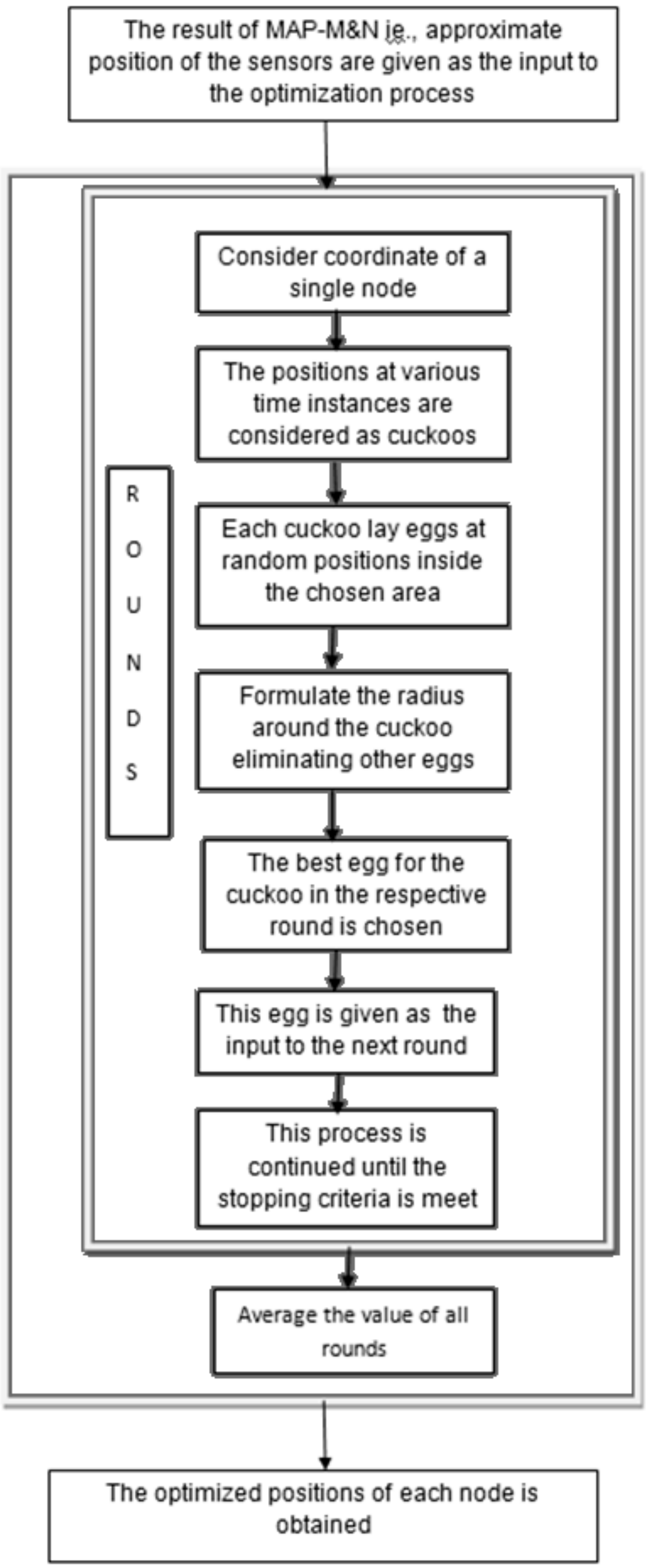


Fig.4. Localization steps used in MAP-M&N with CS-MAP algorithm

4. Simulation Results

The following parameters namely Number of Mobile Anchors, Speed of Mobile Anchors, Number of Sensor Nodes and Execution time are varied and the results were analyzed for each of the parameter variation. From the various simulation studies made on Mobile Anchor Positioning, the following scenario is found as an optimum setup for providing minimal localization error. The following set-up as mentioned in Table 1 was maintained when proposed CS-MAP algorithm was applied over MAP algorithm.

Table 1 Simulation Settings

Number of Sensor Nodes	100
Area of the Sensing Field	1000 X 1000 m^2
Number of Mobile Anchors	3
Speed of Mobile Anchors	100 m/sec
Time interval between successive Anchors	1 sec
Execution time	500 sec
Transmission range	250 m
Routing Protocol	AODV
MAC Protocol	IEEE 802.11

With the above simulation settings in NS-2, the results were analyzed by comparing the performance of Mobile Anchor Positioning (MAP) and proposed CS-MAP evolutionary strategy and the respective graphs were plotted.

4.1 Plots of Calculated Locations versus Actual Locations

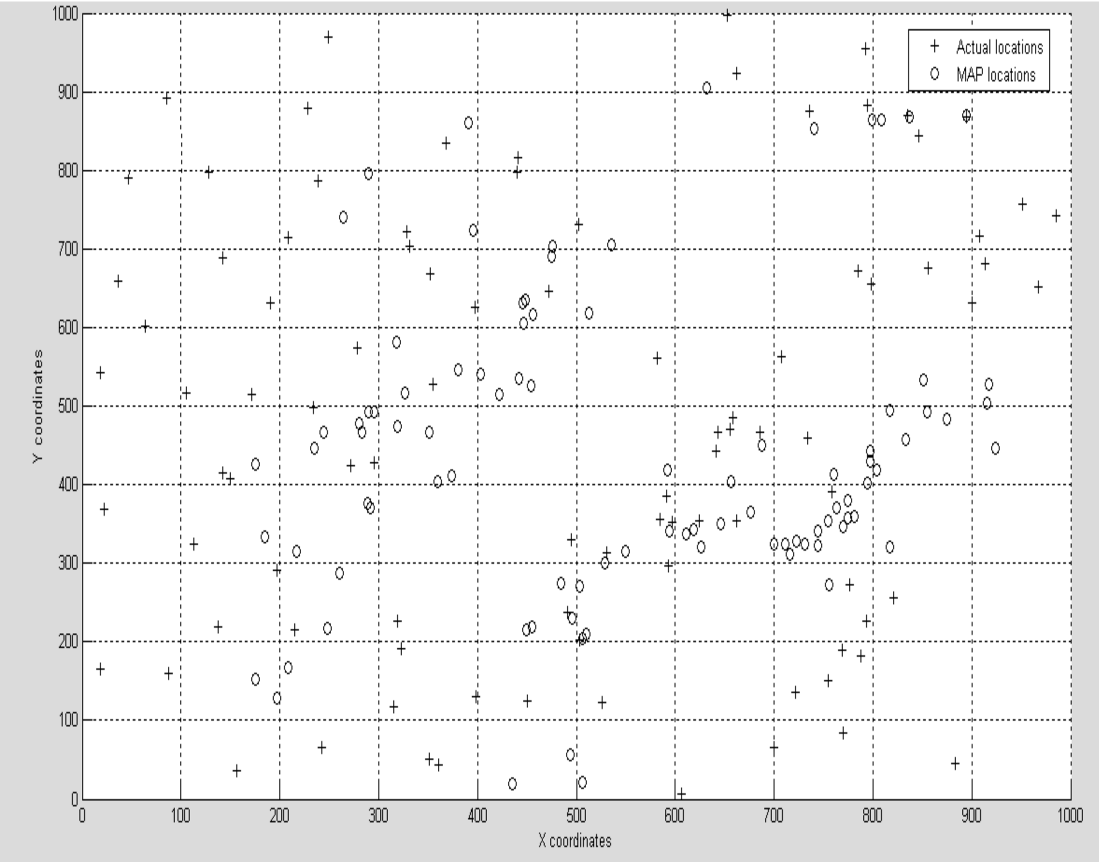


Fig.5. Plot of MAP Locations and Actual Locations

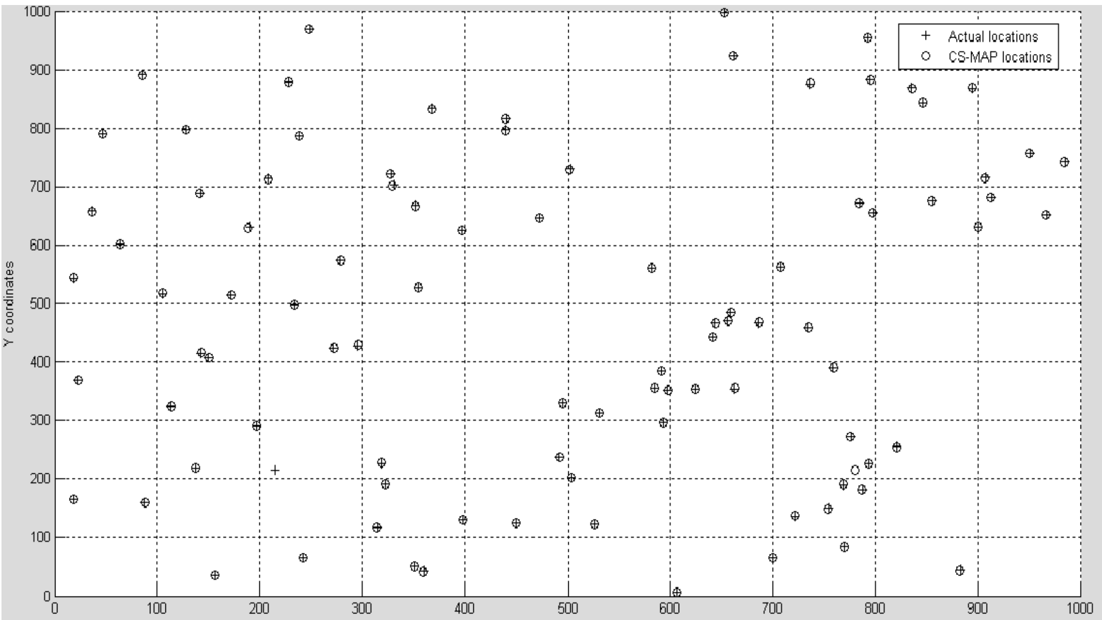


Fig 6. Plot of CS-MAP Locations and Actual Locations

4.2 Metric used to determine Localization Accuracy

The metric that is used to evaluate the accuracy in localization process is Root Mean Square Error (RMSE).

4.2.1 Comparison of RMSE obtained using MAP and CS-MAP approaches

The accuracy in localization can be evaluated based on minimization in positional error. Root Mean Square Error (RMSE) is calculated for both MAP and CS-MAP approaches pertaining to every ten nodes scenario as listed below in Table 2.

Table 2 RMSE Calculation for both MAP and CS-MAP approaches

No. of Nodes	RMSE value obtained using MAP	RMSE value obtained using CS-MAP
10	459.23	5.09
20	212.95	3.71
30	227.51	3.09
40	176.73	2.69
50	305.08	2.45
60	228.20	2.28
70	399.59	2.07
80	246.31	1.94
90	166.96	1.92
100	239.76	1.83

The root mean square error was calculated for both MAP and CS-MAP using the formula,

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(x_{act(i)} - x_{obt(i)})^2 + (y_{act\,(i)} - y_{ol}}{N}} \quad (2)$$

where, x_i , y_i - Actual x and y coordinates of sensor nodes

x_i , y_i - Obtained values of x and y coordinates of sensor nodes

N - Total number of localized nodes

From Table 2, it is observed that the Root Mean Square Error drastically reduces when CS-MAP algorithm is applied along with MAP compared to that produced when only MAP is applied for estimating the location of sensors.

5. Conclusion

MAP uses range-free localization mechanism that does not involve usage of any hardware. In this method, messages containing location information are being shared among the nodes in the field and it does not require flooding and complicated computation for localization. The percentage of localized nodes is high which indicates that MAP method is appropriate for localization purpose. Since this method does not give fine-grained accuracy in localization, optimization techniques are to be applied on the results of MAP. In this paper, CS-MAP algorithm has been applied over MAP to reduce localization error. From the simulation results, it is noticed that localization error is significantly reduced. Cuckoo Search with Mobile anchor positioning (CS-MAP) algorithm significantly brings down the RMSE based localization error by 99.23 % (calculated by percentage error formula) when compared to MAP with regard to 100 nodes scenario.

Thus, it can be concluded that CS-MAP evolutionary approach is better than using MAP alone. Further, modified cuckoo search algorithm can be used instead of cuckoo search algorithm in order to improve localization accuracy further. Moreover cuckoo search algorithm can also be combined with particle swarm optimization (PSO) and similar hybridization of optimization can be applied to further reduce the localization error.

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