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Meta-heuristic approaches for minimizing error in localization of wireless sensor networks

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ABSTRACT

Sensor node localization is considered as one of the most significant issues in wireless sensor networks (WSNs) and is classified as an unconstrained optimization problem that falls under NP-hard class of problems. Localization is stated as determination of physical co-ordinates of the sensor nodes that constitutes a WSN. In applications of sensor networks such as routing and target tracking, the data gathered by sensor nodes becomes meaningless without localization information. This work aims at determining the location of the sensor nodes with high precision. Initially this work is performed by localizing the sensor nodes using a range-free localization method namely, Mobile Anchor Positioning (MAP) which gives an approximate solution. To further minimize the location error, certain meta-heuristic approaches have been applied over the result given by MAP. Accordingly, Bat Optimization Algorithm with MAP (BOA-MAP), Modified Cuckoo Search with MAP (MCS-MAP) algorithm and Firefly Optimization Algorithm with MAP (FOA-MAP) have been proposed. Root mean square error (RMSE) is used as the evaluation metrics to compare the performance of the proposed approaches. The experimental results show that the proposed FOA-MAP approach minimizes the localization error and outperforms both MCS-MAP and BOA-MAP approaches.

1. Introduction

Wireless sensor network 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 [1]. A sensor network is similar to a general purpose mobile ad-hoc network (MANET) in many aspects; they are distributed, self-organized and multi-hopped but it lacks a fixed infrastructure. The main difference [2] lies in the fact that the former has the following constraints: lower cost, lesser bandwidth, smaller processing power, higher redundancy and more power-constrained.

A fundamental problem in designing sensor network is localization [3] i.e. determining the location of sensors. Location information is used to detect and record events, or to route packets using geometric-aware routing. These sensors 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 efficient functioning of WSNs. Location awareness plays an important role in high-level WSN applications like locating an enemy tank in a battlefield, locating a survivor during a natural calamity and in certain low-level network applications like geographic routing and data centric storage.

It is important to note there is an uncertainty on the exact location of sensor nodes. One trivial solution is, equipping each sensor with a global positioning system (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 require some alternative means of localization.

This work is considered suitable for open fields and not for underwater or indoor environments. GPS information of the three anchors is used to calculate the estimates particularly suitable for open fields only and then localization error minimization is performed for the three proposed heuristic approaches. The speed of the mobile anchors is selected as 100 m/s in order to receive more number of beacon packets in a fixed time interval to have a significant increase in the percentage of localized nodes along

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with faster convergence. This is not a generalized procedure for all applications and is applicable only for military applications such as navigation, target tracking, search and rescue and in civilian applications such as disaster relief, time synchronization and surveillance operations. GPS will have limited functionality where line-of-sight (LOS) propagation does not exist. In particular, for indoor applications and under-water sensor networks, GPS will suffer from limited functionality.

Currently, the existing non-GPS based sensor localization algorithms [5] are classified as range-based or range-free methods. Range-based localization schemes rely on the use of absolute point-to-point distance or angle estimate between the nodes. They determine the position of unknown sensor nodes using location-aware nodes which are also called as anchors or beacons. The most preferred range-based localization techniques are received signal strength indicator (RSSI), time difference of arrival (TDoA), time of arrival (ToA), and angle of arrival (AoA). 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 [6] with the aid of extra hardware providing high localization accuracy. Hence, the uses of range-based methods are generally not 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 be used with anchors or beacons. They do not require complex hardware and they are cost effective 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 and Distance Vector Hop (DV-Hop) Algorithm are examples for range-free algorithms. Range-free algorithms sometimes use mobile anchors for localization.

Localization problem can be mathematically stated as follows: consider a network formed by $L = M + N$ sensor nodes, where M represents the anchor nodes and N represents the non-anchor nodes. The anchor node is defined as a node that is aware of its own location, either through GPS or manual recording and entering position during deployment [7]. Anchor node position is expressed as $a_k \in \Re^n$, $k = 1,2,\ldots, M$ in n-dimensional coordinates. The non-anchor node is defined as a node that is unaware of its own location. Non-anchor node position is expressed as $x_j \in \Re^n$, $j = 1,2,\ldots, N$ in n-dimensional coordinates. The goal of a location system is to estimate coordinate vectors of all N non-anchor nodes. Generically, the localization schemes operate in two phases:

Phase 1: Inter-node distances estimation based on hop connection information or true physical distance calculation based on the inter-node transmissions and measurements.
Phase 2: Transformation of calculated distances into geographic coordinates of nodes forming the network.

The standard approach is to formulate localization problem as an optimization task [8] with the nonlinear performance function J_N as given by Eq. (1):

$$\min_{\tilde{X}} \left\{ J_N = \sum_{K=1}^{M} \sum j \in S_k(\hat{d}_{kj} - \tilde{d}_{kj})^2 + \sum_{i=1}^{N} \sum j \in S_i(\hat{d}_{ij} - \tilde{d}_{ij})^2 \right\} \tag{1}$$

where $\hat{d}_{kj} = ||a_k - \hat{x}_j||$, $\hat{d}_{ij} = ||\hat{x}_i - \hat{x}_j||$, a_k denotes the real position of the anchor-node k, $\hat{x}_i$ and $\hat{x}_j$ denote, respectively, the estimated positions of nodes i and j, $\hat{d}_{ij}$ and $\hat{d}_{kj}$ are the estimated distances between pairs of nodes calculated based on measurements, and S_i, S_k are sets of neighboring nodes defined by Eqs. (2) and (3) as follows:

$$S_k = \{(k, j) : ||a_k - x_j|| \le r_k\}, \quad j = 1, 2, \ldots, N \tag{2}$$

$$S_i = \{(i, j) : ||x_i - x_j|| \le r_i\}, \quad j = 1, 2, \ldots, N \tag{3}$$

where x_i and x_j denote real positions of nodes with unknown locations and r_i and r_k their corresponding transmission ranges. Various optimization techniques are used to solve the optimization problem as defined by the above Eq. (1). Hence, there is a need to choose an algorithm or technique that efficiently eliminates localization errors and optimizes the obtained locations such that it brings forth better accuracy in localization. Many researchers have suggested the use of heuristic methods and hence three meta-heuristic optimization techniques have been proposed in this work to minimize the error in localization.

Localization in wireless sensor networks is considered as intrinsically an unconstrained optimization problem [9]. The proposed meta-heuristic optimization approaches namely, Bat Optimization Algorithm, Modified Cuckoo Search algorithm and Firefly Optimization Algorithm have been applied over the initial location estimation using Mobile Anchor Positioning (MAP). The MAP is a range-free approach, where the anchor nodes broadcast their location while moving and the obtained localization result is optimized by means of the optimization strategies as stated above.

The remainder of this paper is organized as follows: Section 2 categorizes the related research and reviews the relevant literature. Section 2.1 enumerates the pros and cons of some existing range-based localization approaches. Section 2.2 highlights the pros and cons of some existing range-free localization approaches. Section 2.3 highlights the pros and cons of some existing hybrid localization approaches. Section 2.4 discusses the pros and cons of some existing mobile anchor based localization approaches. Section 2.5 discusses the pros and cons of some existing evolutionary based localization approaches. Section 3 elaborates on proposed meta-heuristic approaches for localization. Section 3.1 illustrates the range-free localization approach namely, Mobile Anchor Positioning (MAP). Section 3.2 depicts the flowchart for localization steps used in Bat Optimization Algorithm with MAP (BOA-MAP). Section 3.3 portrays the flowchart for localization steps followed in Modified Cuckoo Search with MAP (MCS-MAP) Algorithm. Section 3.4 lists the localization steps for Firefly Optimization Algorithm with Mobile Anchor Positioning (FOA-MAP) and its flowchart. Section 4 details on the experimental results, simulation settings in NS-2, RMSE table and graph for comparing performance of the three proposed meta-heuristic approaches. Section 5 discusses the concluding remarks and the scope for future research.

2. Literature review

Localization techniques in the literature are categorized as range-based localization techniques, range-free localization techniques, hybrid localization techniques, mobile anchor based localization techniques and evolutionary based localization techniques.

2.1. Reviews on range-based localization techniques

Range-based localization techniques rely on the availability of distance (or) angle information between the nodes to determine the unknown sensor node's position. Sensor nodes are equipped with extra hardware, which is capable of estimating distance (or) angle by means of techniques such as received signal strength indicator (RSSI), time of arrival (ToA), time difference of arrival (TDoA), (or) the angle of arrival (AoA). The typical geometrical approaches widely used for location estimation are Tri-lateration and Multi-lateration. Inspite of requiring extra hardware, the range-based localization techniques have the advantage of fine resolution. In addition, the localization precision of range-based approach is higher than that of the range-free approach.

Mayuresh Patil et al. [10] had proposed a distributed localization scheme based on received signal strength indicator (RSSI) by the three masters. The actual location was calculated from the received signal strength (RSS), which gives the distance information. The distance from three masters is determined and the sensor node can compute its location by using circular triangulation concept. The relationship that is used to calculate the distance, from the RSS value, is as stated in Eq. (4):

$$\frac{P_r}{P_t} = \frac{A_{er}A_{et}}{r^2\lambda^2} \tag{4}$$

where P_r and P_t denote the received power and transmitted power in Watts respectively. A_{er} and A_{et} are the effective apertures of the antenna transmitter and receiver in m^2 respectively; r denotes the distance in meters and λ denotes the wavelength in meters. The simulation was performed by considering a sensor network having sensor nodes placed in a square region of size 100 units × 100 units area and with 100 and 1000 nodes. The simulation using one master method based on RSSI was performed. At first the relative distances computed comes to the master (beacon node) and then the beacon calculates the location of the nodes and transmits the entire information back to the nodes. Though one master method was accurate, it requires high power beacon and a lot of power wastage occurs while transmitting the relative distances to the master. The two master methods for localization uses two high power beacons and unknown sensor node detects the signal strength from these two beacons, calculates its location using circular triangulation. Disadvantages of two master method is it requires two high power beacons and also ambiguity arises while calculating the unique location using two beacon nodes and localization has to be done frequently wasting the power. The three master methods uses three beacons and the advantage in this localization method is that the beacon power required will be the same as any other ordinary node and any node in the network can work as a beacon. The other advantage is that the communication overhead required is reduced and during localization, the anchors or beacons back-off by a random time interval. This reduces collisions and hence retransmissions. This also reduces the power consumption and the localization time of the network. Based on the simulation results, with regard to the localization error and power consumption, the authors have verified that the three master approach performs relatively much better than two-master and one master approaches. Unlike ToA and TDoA, the RSS algorithm works not on signal delay but on signal strength analysis.

Xiao et al. [11] had proposed TDoA for localizing the sensor nodes. TDoA algorithm operates by considering a transmitter P that sends a message, then analyzing the received signal correlation (delay) in more than two receivers it becomes possible to compute the distances between the point P (whose position is to be computed) and each receiver (whose positions are known). TDoA requires time difference of arrival of the signal from the unknown node to the two different beacon or anchor nodes but do not require the propagation time. Hence, the time synchronization between anchor nodes and unknown nodes is reduced.

Peng and Sichitiu [12] had proposed a probabilistic localization scheme using angle of arrival (AoA) which is susceptible to measurement noise and other problems if the unknown sensor nodes are unable to hear directly from a sufficient number of beacons. Probabilistic localization scheme is such that instead of maintaining a single hypothesis on the configuration, it maintains a probability distribution over the space of all possible hypotheses. The authors termed this localization as probabilistic since the measurement; noise is modeled probabilistically and the algorithm utilizes the model to localize the unknowns. The position information of the beacons and the AoA information at each unknown are flooded within a limited number of hops. The position of each sensor node is determined using a probability density function of the two-dimensional coordinate random variable (X,Y) in a collaborative and distributive manner. By using both the position of the beacons and the AoA measurements, each unknown sensor node determines it position. The simulation results convey that even with inaccurate AoA measurements and a small number of beacons, the proposed approach achieves both very good accuracy (i.e. difference between the real position of nodes and calculated position by the localization algorithm) as well as precision (i.e. the uncertainty in the position estimate) compared to the results with simulation results of ad hoc positioning system (APS) + angle of arrival (AoA) based localization. The proposed approach also achieves much better coverage than the existing APS + AoA scheme.

Chaczko et al. [13] has suggested time of arrival (ToA) for localizing the sensor nodes. ToA algorithm principally operates by considering the signal delay. If a sensor P with unknown position (x, y) sends a signal $s(t)$, then the received signals are generally computed using the relationship as shown in Eq. (5):

$$y_j[t] = k \cdot s(t - t_j) \tag{5}$$

where j = 1, 2, 3 refers to receivers located in the known positions (x_j, y_j). Assuming that perfect synchronization distances exist between the transmitter P and the receivers, then computation of $y_j[t]$ becomes much easier. Similar to the TDoA technique, this time of arrival technique only differs by means of using the absolute time of arrival at a certain base station rather than the measured time difference between departing from one and arriving at the other station. The distance can be directly calculated from the time of arrival as signals travel with a known velocity. As with TDoA, synchronization of the network base station with the locating reference stations is important. The demerit of this approach is that ToA definitely needs strict time synchronization of the whole network, which is hard to achieve in practice.

Mustapha et al. [14] has proposed a new localization algorithm, high accuracy localization based on angle to landmark (HA-A2L). Landmark is the term used to indicate the positioned nodes. This new protocol allows nodes to exchange information pertinent to localization process and a localization algorithm that uses estimation of distances and incoming angles to locate the non-positioned nodes in sensor networks. The AoA technique used here is obtained by means of an antenna array. Triangulation technique can be adopted in order to compute the distance between the nodes, provided the angles of arrival between the neighboring nodes are known. After the distance computation, either trilateration (or) multilateration techniques are used to calculate the positions of nodes. Thus, the localization algorithm followed by the authors improves the coverage and produces highly accurate location positions compared to many other existing methods. The demerit observed is that after distance computation if trilateral localization is used, then it not only produces large location errors but also easily tends to an abnormal phenomenon. Also distance computation is possible only if the angles of arrival between the neighboring nodes are known.

Kuruoglu et al. [15] have proposed the three dimensional adapted multi-lateration (3D-AML) technique for handling the distance measurement errors in three-dimensional environments. 3D-AML is an extension of 2D-AML, which follows the concept of intersecting spheres in 3D and the geometric properties to calculate the location of a sensor node, which is exactly similar to the concept of intersecting circles in 2D environments. 3D-AML performance is compared with the conventional multi-lateration technique of GPS. The simulation results proved that the 3D-AML method has lower

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localization error than the conventional multi-lateration technique of GPS for noisy measurements, when the Modeling of ranging errors is done with Gaussian distribution having zero mean and varying standard deviations. Generally, ranging errors affect the accuracy of estimated positions but this 3D-AML is robust against ranging errors, provides lightweight and accurate localization. This robust localization scheme is useful if the distance measurements to anchors can be retrieved using any of the conventional ranging methods and can be modified to support Mobile WSN. In addition, the AML is advantageous for iterative localization, since the localized nodes become reference nodes and employed in the process of localization.

Shaoping et al. [16] has proposed the Iterative multilateral localization algorithm based on Time rounds (IMLBTR). The triangular placement scheme can reduce error accumulations by reducing the number of iterations. But trilateral localization not only produces large location errors but also easily lend to an abnormal phenomena. One such algorithm suggested as an alternative is the Iterative multilateral algorithm based on Time rounds. In this IMLBTR method, an unknown node estimates its location and it becomes a beacon node and broadcasts its location to neighboring nodes, by which those nodes estimate their position. This algorithm introduces time round scheme, localizes round after round, and it limits the minimum number of neighboring beacon nodes that localization requires in different time rounds. In first round, localization based on anchors, all unknown nodes, whose neighboring nodes have three or more anchors, are localized. In subsequent rounds, the calculated sensor nodes also becomes anchor nodes and gets added to anchor nodes list and proceed computing the positions of remaining nodes. This process continues until all the nodes position in the region of interest was found.

Some common limitations that can be observed from these range-based approaches are the following:

1. Assuming that perfect synchronization distances exist between the transmitter P and the receivers, which need not be the case always in reality.
2. The cost encountered will be more if one of the conventional ranging methods (which involve hardware) is used while retrieving the distance measurements to anchors.
3. The approaches increase the computation time for localization of the sensor nodes.
4. There may be a greater chance of positional error of nodes getting propagated from one round to the other as the localization process is iterative.

2.2. Reviews on range-free localization techniques

The range-free (or) proximity based localization techniques does not depend on distance (or) angle information but they depend on the topology and connectivity information to determine the unknown sensor node's position. In range-free localization schemes, the position of the sensor node is determined based on information transmitted by nearby anchor nodes (or) neighboring nodes, based on hop (or) triangulation basis. Range-free localization techniques are cheaper when compared to range-based techniques. Some of the typical range-free approaches are approximate point-in-triangulation test (APIT), centroid scheme, distance vector (DV) – hop scheme and amorphous scheme.

Chong Liu and Kui Wu [17] have performed the performance evaluation especially on two novel Range-free localization techniques namely APIT and ring overlapping based on comparison of received signal strength indicator (ROCRSSI). This performance evaluation was to alleviate effectively the APIT's inherent "undetermined node" problem and for achieving higher estimation accuracy with lower communication overhead. This work investigates the system configurations, which directly influence the performance of APIT and ROCRSSI, including anchor deployment strategies, which is seldom addressed by most of the existing works. The simulation results are appealing since under the same system configuration, ROCRSSI outperforms APIT in terms of both estimation accuracy and energy efficiency.

Deng et al. [18] has proposed centroid localization algorithm, in which the anchor or beacon nodes broadcast their positions and each sensor node will calculate its position as a center of the connected anchor nodes. Centroid localization algorithm is simple and economical but it depends on a number of anchor nodes. This is because for the purpose of good localization, all the sensor nodes must be connected to the anchor node. It is observed that the centroid localization algorithm may cause large error and the localization precision will drop because of the set of asymmetrical reference anchor nodes distributed around the unknown node.

Ji Zeng and Hongxu [19] have proposed an improved APIT algorithm for location estimation in WSN. In this APIT range-free localization algorithm, the location estimation was performed by means of isolating the environment into triangular regions between the anchor nodes. Based on the presence of each sensor node inside or outside of those triangles, the possible likely area has been narrowed down in which the node can reside and then compute the centroid of polygons. The basic concept of APIT algorithm is that the unknown node first hears the information of all the nearby anchors. Then all triangles are formed by connecting every three anchors, which are selected from these anchors in the ergodic. Now test the node whether it is within each triangle or not. Finally, the center of gravity (COG) of the intersection of all of the overlap triangles is calculated in which the node resides to determine its estimated position. The improved APIT algorithm that is proposed in this work performs best when compared to the original APIT algorithm, based on the metrics such as high node packet loss rate and node density. The main drawback in APIT approach is that the sensor nodes must be connected to a number of anchor nodes.

Kenneth et al. [20] have suggested a classical protocol for centralized localization method called as semi-definite programming (SDP) for sensor network node localization with the use of incomplete and noisy distance measurements between the nodes as well as anchor position information. They have performed this work for the proposed SDP and Edge-based SDP schemes especially in the presence of uncertainties namely-anchor position uncertainty, propagation speed uncertainty and combining both these uncertainties. The Computational time and Mean square error (MSE) were compared to the proposed SDP and Edge-based SDP. The results conveyed that proposed SDP could give very accurate node localization than standard SDP, only when the anchor positions are of errors. The limitation observed is that the results of simulation inferred that Edge-based SDP scheme is much more computationally efficient than the proposed SDP scheme, provided the MSE values are higher.

Gao and Lei [21] have suggested that traditional DV-Hop algorithm can be applied in three steps. In the first step, all anchor nodes broadcast a beacon message to all the other nodes. The format of the beacon message is {id, x_i, y_i, Hop count} and then it flooded through the whole network. The initial value of Hop Count is zero. In the second step, the anchor nodes get minimum hop count value to the other anchor nodes according to the result in the first step. In the third step, the unknown node can calculate their location based on least square method. DV-Hop algorithm is a range free algorithm which employs a classical distance vector exchange so that all nodes in the network get the distances, in hops to the anchors. Then the average hop distance was calculated and should be applied to the sensor nodes for localization. Since the sensor and anchor nodes are placed uniformly in the entire area, DV-Hop method works well in the case of isotropic networks. It can be observed from the DV-Hop scheme that since the nodes are not uniformly distributed, the relationship between hop counts and geographic distances are weak, which results in large errors while considering anisotropic networks.

The Amorphous algorithm is similar to DV-hop algorithm, but it assumes to know the network density in advance. It uses offline hop-distance computations, improving the location estimates through a neighbor-information exchange. It is to be noted that APIT, Centroid, DV-Hop and Amorphous schemes are all distributed algorithms and they are characterized by simple computation, reduced traffic and better scalability.

Lee et al. [22] have proposed a new robust range-free localization algorithm called optimal proximity distance map using quadratic programming (OPDMQP). Unlike other algorithms focusing on isotropic networks, the proposed algorithm works well not only in isotropic networks but also in anisotropic networks. Mathematical modeling is performed to establish a relationship between proximity within the sensor nodes and geographical distances in a wireless sensor network. OPDMQP algorithm defines a set of constraints on the given network topology and formulates the localization problem into a quadratic programming (QP) problem. The proposed OPDMQP resolves the problem of proximity distance map (PDM) by embedding the constraints of WSNs into the localization problem. The proposed method was demonstrated to be superior in two types of anisotropic networks namely C-shaped topology and X-shaped topology. The proposed OPDMQP method outperforms other methods in terms of localization error and hence results in reliable localization estimates.

Some common limitations observed from these range-free approaches are the following:

1. The observation is that, these approaches are not robust to the interference of environment noise and only provide coarse-grained accuracy.
2. The approaches take more computational time for finding the positions of sensor nodes.

2.3. Reviews on hybrid localization techniques

Hybrid localization techniques can combine simple geometry of triangles and stochastic optimization algorithms (or) it can be two geometrical approaches combined (or) it can be two stochastic optimization algorithms for estimating the position of non-positioned nodes in a WSN.

Minghui and Yilong [23] have proposed an algorithm for accurate narrowband angle of arrival (AoA) estimation in unknown noise fields and harsh WSN scenarios. A maximum likelihood (ML) criterion was derived w.r.to AoA and unknown noise parameters, since noise covariance is modeled as a linear combination of known weighting matrices. They have proposed particle swarm optimization (PSO) for tackling the cost function in ML criteria in an efficient manner. The simulation results demonstrated that especially in unfavorable scenarios, PSO-ML significantly outperforms other popular techniques and produces superior bearing estimates. The demerit observed is that the performance of PSO-ML criterion was not tested in favorable scenarios of WSN.

Zhang et al. [24] proposed a Genetic Simulated Annealing algorithm based Localization (GSAAL) algorithm for wireless sensor network (WSN). The proposed algorithm adopts two new genetic operators namely, single-vertex-neighborhood mutation and the descend-based arithmetic crossover. Genetic Algorithm is good at global search but is poor at local search. The advantage of using simulated annealing (SA) algorithm is it attempts to avoid being trapped in a local optimum by sometimes allowing the temporal acceptance of inferior solutions. During searching for the optimal solution, SAA not only accepts optimal solutions, but also accepts the degraded solutions at a certain degree. SA is good at local search. The merit of this algorithm observed from results of simulation is that it can achieve higher accurate position estimation and can improve the calculation efficiency greatly than the semi-definite programming with gradient search localization (SDPL).

2.4. Reviews on mobile anchor based localization techniques

Ssu et al. [25] presented a range-free algorithm, which uses the following conjecture. A perpendicular bisector of a chord passes through the center of the circle. When there are two chords of the same circle, their perpendicular bisectors will intersect at the center 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 center of a circle and determines its location by finding the intersection point of the perpendicular bisectors of the constructed chords. With this scheme, no extra hardware or data communication is required for the sensor nodes and also obstacles in the sensing field can be tolerated. Simulation results predict that this scheme performs better than other range-free schemes.

Zhen Hu et al. [26] 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. The demerit observed in this scheme is that the authors use simulation and tests only from an indoor deployment to investigate the localization accuracy and can provide flexible accuracy but not high accuracy.

Zhang Baoli et al. [27] 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 centers. Four-intersection points s_1, s_2, s_3, s_4 of the circles are calculated. Then using the centroid formula on these four intersection points, the position of the sensor node is calculated. The limitation that can be observed is that the node positions can be determined accurately only if the beacon operates along straight-line traverse routes which need not always be realized in practice.

Hung Wu et al. [28] 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. Simulation results show that this scheme is very efficient and the node positions can be determined accurately.

Karim et al. [29] 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_Method 1 as well as RELMA_Method 2 has 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_Method 1 and RELMA_Method 2 are compared only with the existing neighboring-information-based

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localization system (NBLS). Simulation results demonstrate the fact that RELMA_Method 1 and RELMA_Method 2 outperform NBLS in terms of localization accuracy as well as energy efficiency. The demerit observed is that for computing the node positions, the authors have used only the sensing range for each pair of nodes to communicate instead of the communication range which need not always be the case when it is realized in practice.

Huan-Qing et al. [30] 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. It is observed that for estimating the node positions, the authors have used distances to three beacons and also weighted centroid localization method which increases the computation time during localization process.

Liao et al. [31] 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 center. 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. Demerit noticed in this approach is that the un-localized nodes compute their locations due to beacon packets broadcasted from mobile anchors and also from stationary localized nodes leading to limitation in communication cost and also provide only coarse-positioned location accuracy.

Some common limitations that are observed from these mobile anchor based approaches are the following:

1. In these approaches their accuracy will not be very high i.e. only coarse-positioned accuracy is achieved unlike the fine-grained accuracy in range-based localization.
2. In these approaches, it is observed that after the first round localization is performed, the un-localized sensor nodes can compute their locations with the help of localized stationary sensor nodes, which leads to limitation in communication cost not only due to beacon packets broadcasted from mobile anchors but also by the packets broadcasted by stationary localized sensor nodes.

2.5. Reviews on evolutionary based localization techniques

Gopakumar and Jacob [32] 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 neighboring anchor nodes. The PSO algorithm provides better convergence than simulated annealing and ensures solution without trapped into local optima.

Yu zeng et al. [33] proposed a novel WSN node localization algorithm based on an improved simulated annealing algorithm. Simulation results demonstrate the fact that this algorithm achieves superior performance when compared to traditional simulated annealing algorithm and the positioning accuracy has increased nearly doubled. In addition, the algorithm is very simple and the computational loads are very small, therefore it is suitable for node location of wireless sensor network.

Wenwen and Wuneng [34] 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 performed and the solution is obtained with high accuracy. The above genetic algorithm approach gives good localization accuracy. The demerit observed in this method is that, the solution space is very huge and 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.

Jia Huan and Wang [35] 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 toward the actual coordinates. As the genetic algorithm is iterative – looped, the localization accuracy is improved to some extent. The merit observed in this proposed localization algorithm when compared to genetic algorithm proposed by Wenwen et al. [34] is that this algorithm need not search for a large number of solutions in each of the iterations and also the solution space is relatively smaller. The demerit noticed in proposed weighted centroid combined with genetic algorithm is that it provided only coarse-positioned location accuracy.

Lei et al. [36] proposed a Mobile Anchor Assisted Localization Algorithm based on PSO (MAAL_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. The demerit observed from this proposed method is grid (uniform) deployment of sensor nodes used in the ROI is not applicable as the sensor nodes are generally noticed to be randomly deployed for real-time environments.

Han Bao et al. [37] 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 and also to a Mobile Anchor Assisted Localization Algorithm based on particle swarm optimization proposed by Lei et al. [36].

Some common limitations that can be observed from these evolutionary based approaches used for localization are the following:

1. The observation is that, these evolutionary based approaches considered are not robust to the interference of environment noise.
2. These approaches are suitable for node location of wireless sensor network only when the computational loads are very small.
3. In these approaches, each mobile anchor broadcasts beacons periodically, and the sensor nodes can locate themselves only upon the receipt of multiple beacon messages, which in turn increases the computational time during localization process and also provides only coarse-positioned location accuracy.

Based on the literature review done, it is identified that the range-free localization schemes, does not involve the usage of any hardware and hence the cost is reduced when compared to range-based localization schemes. It is necessary to propose suitable evolutionary approaches for localization to be combined with mobile anchor positioning (MAP) method, a range-free localization scheme in order to minimize the localization error further. Though the percentage of localized nodes in MAP method is high indicating that it is appropriate for localization purpose, but it does not guarantee fine-grained accuracy in localization and therefore evolutionary algorithms are needed to be applied over the results of MAP for minimizing localization error largely. In order to avoid being trapped into local minima as well as to provide faster convergence, it is essential to apply certain meta-heuristic techniques over the results of MAP method in order to minimize the localization error far better than the existing approaches specified in the literature.

Many design optimization problems are highly non-linear, which can typically have multiple modal optima and so it is challenging to solve such multi-modal problems. In order to understand this issue, traditionally considered global optimization algorithms are applied but could not produce good results. The latest trends are to apply new meta-heuristic algorithms [38]. A meta-heuristic algorithm is also a heuristic algorithm, but considered as a more powerful one, since it is a mechanism that avoids being trapped in a local minimum. Moreover, the meta-heuristic is able to employ heuristics methods by guiding them over the search space in order to exploit its best capabilities to achieve better solutions. In many instances, a heuristic method provides a result that is “good enough”. Heuristic algorithms use the trial-and-error, learning and adaptation to solve problems. We cannot expect them to find the best solution all the time, but expect them to find good enough solutions or even the optimal solution most of the time, and in a reasonably and practically short time [39]. The heuristic methods are used for their speed, while the other methods can be very expensive when considering computing resources. Thus a heuristic method can balance the quality of the result with the time spent on computation. It is possible that the heuristic method fails on certain instances (it cannot find any result), but these situations are extremely rare. Meta-heuristic is a framework that gives directions on how to solve a set of problems. Modern meta-heuristic algorithms are almost guaranteed to work well for a wide range of tough optimization problems. The successful meta-heuristic techniques [40] are inspired by nature as they have been developed based on some abstraction of nature. Certain meta-heuristic approaches proposed in this paper with Mobile Anchor Positioning (MAP) method are Bat Optimization Algorithm with MAP (BOA-MAP), Modified Cuckoo Search with MAP (MCS-MAP) algorithm and Firefly Optimization Algorithm with MAP (FOA-MAP). The location of nodes is initially estimated using MAP. Then the proposed meta-heuristic approaches are applied over the results obtained by MAP. The observation is that, when FOA is applied over the results of MAP, it estimates the location of the sensor nodes providing very high accuracy better than MCS-MAP as well as BOA-MAP approaches.

3. Proposed meta-heuristic approaches for localization

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, which offers coarse-grained accuracy is used, the obtained location will be just an estimate. In the second phase (post optimization phase), Bat Optimization Algorithm with MAP (BOA-MAP), Modified Cuckoo Search with MAP (MCS-MAP) algorithm and Firefly Optimization Algorithm with MAP (FOA-MAP) are applied over the results of MAP in order to enhance the localization accuracy further.

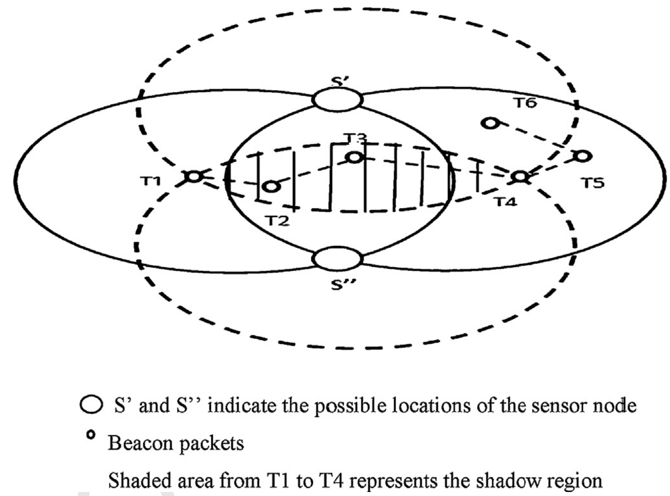

Fig. 1. Node seeking information from neighbor sensors.

3.1. Mobile Anchor Positioning (MAP)

The simulation environment is set-up as follows: the sensor nodes are randomly deployed in the sensing field. The assumption made during simulation is that the Mobile anchors, which are location aware nodes move throughout the sensing field according to the positional data specified in a movement file, which is given as input to the network simulator (NS-2). 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 s. 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 will begin at that particular node.

Assumption made in the simulator is that same transmission range is used for all the sensor nodes as well as mobile anchor nodes and each mobile anchor broadcasts a beacon packet per second. This is followed because the comparison will be valid with the three proposed heuristic approaches and with MAP only in the same transmission range. No specific mobility model is considered when designing these approaches and experiments. Instead of using random way point mobility model, the mobile anchor nodes in the proposed approaches have been given a predefined (regulated) movement based on a movement file which is fed as input to NS-2 simulator and not random movement.

Assume that the sensor node has received and stored four beacons (locations of the mobile anchor) in its list $\{T_1, T_2, T_3, \text{and } T_4\}$ as shown in 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 centers and the communication range of a sensor node as radius, two circles are constructed. 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 of both circles. Hence, it can be concluded that circles will intersect each other.

The intersection points of both circles are determined (S_1, S_2) which 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. 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 circles. The points which are satisfying the above condition are known as intersection points. By means of Mobile Anchor Positioning, the location of the sensor node has been approximated to two locations.

3.1.1. Identifying the sensor locations using MAP with Mobile Anchor (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 a 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 $\{T_1, T_2 \ldots T_n\}$. The beacon points are the two extreme points i.e., T_1 and T_n. Beacon points are called as extreme points because the mobile anchor nodes broadcast beacons periodically during every time interval, which is received by unknown sensor nodes that fall inside the communication range of mobile anchor. When the mobile anchors continue broadcasting beacon packets, after a particular time interval, there will be an idle period for mobile anchors which clearly indicates that the respective beacon points serve as the two extreme points. Two circles with radius R and center T_1 and T_n are constructed and their intersection points of them are found to be S' and S''.

If there is any Ti ($2 \le i \le n-1$), such that the distance between Ti and S' is less than R and that between Ti and S'' is greater than R, we can conclude the location of the sensor node as S'. It 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. 1. If all the Beacon points lie inside this region, it will not be 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 center and the shadow region is the intersection of the two circles. 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. 1.

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, 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 & Neighbor (MAP-M&N) is being adopted.

3.1.2. Forming additional anchors and identifying the sensor locations using MAP with Mobile Anchor & Neighbor (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. 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.

3.1.3. MAP-M&N algorithm procedure

The steps involved in finding the location of the sensors in the field using MAP-M&N algorithm are as listed below:

1. Deploy 100 sensor nodes randomly in the 1000 m × 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 Mobile Anchor nodes move throughout the sensing field according to the positional data specified in the movement file which is given as input to the NS-2 simulator. They 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. Visitor list corresponds to the list of anchor node's coordinates stored every time in the unknown sensor nodes for determining its position.
4. The sensor nodes can identify the farthest beacon packets and choose those beacon packets as beacon points.
5. With those two beacon points as the centers 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, at least one of the beacon points in the visitor list must lie outside the shadow region or based on the beacon points obtained from the neighboring nodes.
7. The approximate location for each of the sensor nodes is estimated using MAP-M&N method.

3.2. Bat Optimization Algorithm with Mobile Anchor Positioning (BOA-MAP)

Bat algorithm is based on the echolocation features of microbats. The algorithm follows frequency-tuning technique to increase the diversity of solutions in the population, while at the same, it uses the automatic zooming to try to balance exploration and exploitation during the search process by mimicking the variations of pulse emission rates and loudness of bats when searching for prey. As a result, it proves to be very efficient with a typical quick start. The Bat algorithm [41] was developed with the following three idealized rules:

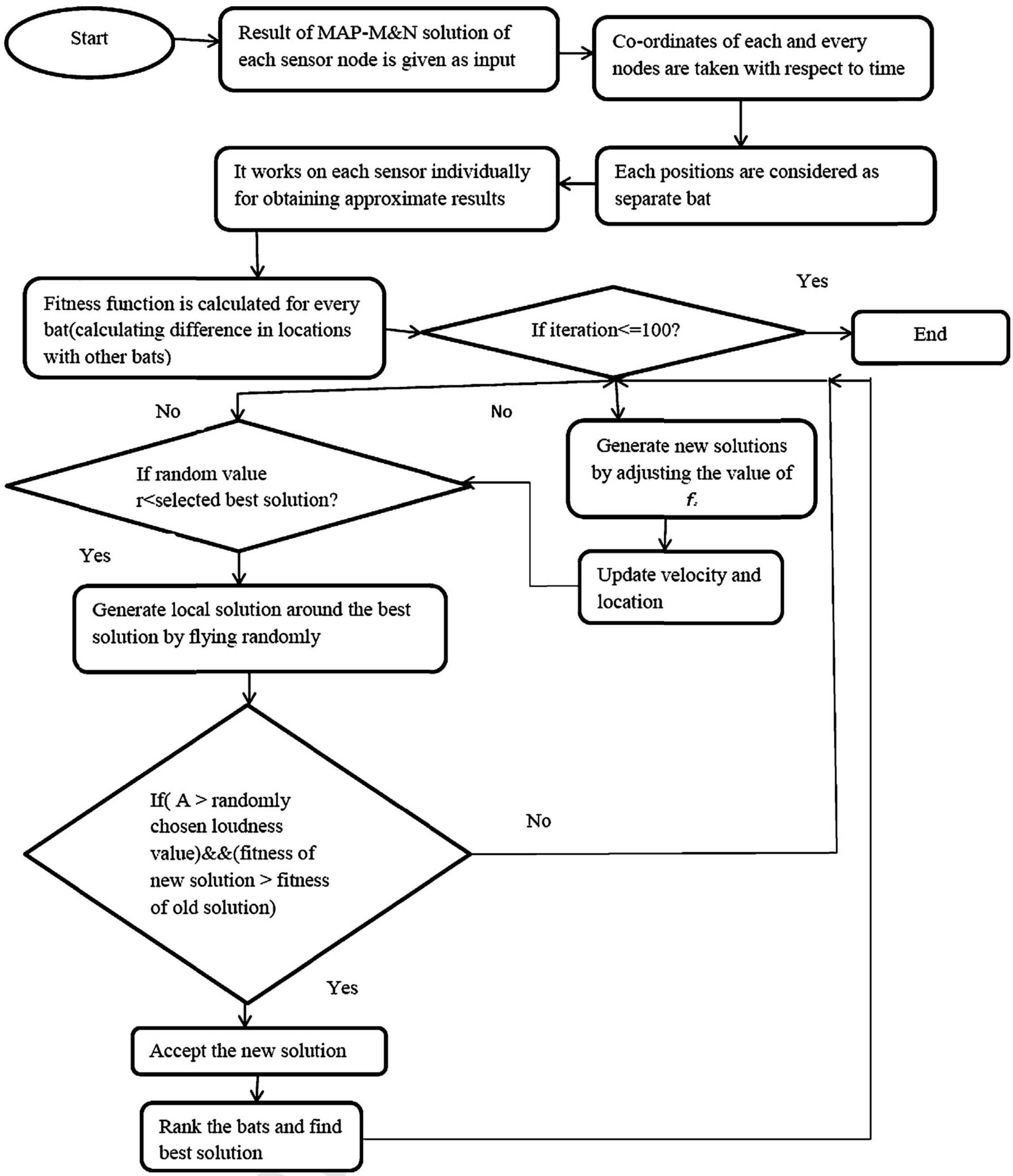

Fig. 2. Localization flowchart for BAT Optimization Algorithm with MAP (BOA-MAP).

1. All bats use echolocation to sense distance, and they also 'know' the difference between food/prey and background barriers in some magical way.
2. Bats fly randomly with velocity v_i at position x_i with a frequency f_{min}, varying wavelength λ and loudness A_0 to search for prey. They can automatically adjust the wavelength (or frequency) of their emitted pulses and rate of pulse emission ∈[0,1], depending on the proximity of their target.
3. Although the loudness can vary in many ways, we assume that the loudness varies from a large (positive) A_0 to a minimum constant value A_{min}.

The localization steps followed in WSN using Bat Optimization Algorithm (BOA) is as depicted in the flowchart shown in Fig. 2.

3.3. Modified Cuckoo Search with Mobile Anchor Positioning (MCS-MAP) Algorithm

The proposed evolutionary strategy applied along with the results of MAP-M&N as input is the Modified Cuckoo Search (MCS) [42] optimization algorithm, which is one such evolutionary algorithm inspired by the lifestyle of the cuckoo bird.

Each cuckoo lay eggs [43] at random positions inside the chosen area around it with a radius as stated by,

$$r = \left[\frac{\text{number of eggs per cuckoo}}{\text{sum}}\right] * [\text{radius Coeff} * (varHi - varLo)] \quad (6)$$

MCS algorithm makes two variations while comparing with Cuckoo Search Optimization algorithm. The first variation

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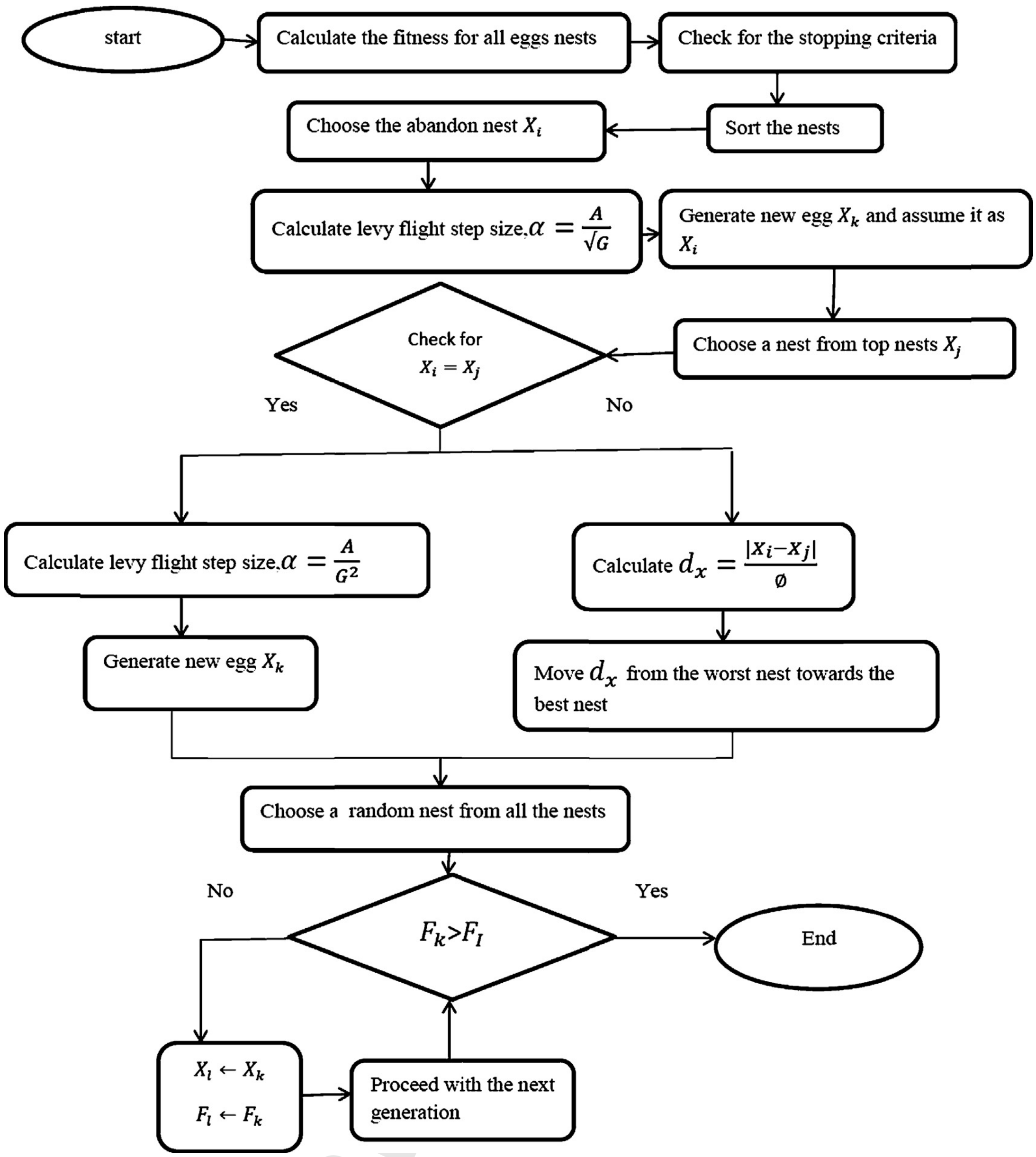

Fig. 3. Flowchart for localization steps in Modified Cuckoo Search with MAP (MCS-MAP).

encourages more localized searching and the second variation brings about the replacement of eggs with lesser profit. Modified Cuckoo Search (MCS) meta-heuristic is applied for unconstrained optimization problems. Mature cuckoo's lay egg in other bird's nests, the eggs hatch and grow if they are not identified by the host birds and destroyed. The ultimate aim is to find the best habitats leading to the global maximum of objective functions.

The steps in finding the location of the sensors in the field using MCS-MAP algorithm as depicted in the flowchart shown in Fig. 3.

3.4. Firefly Optimization Algorithm with Mobile Anchor Positioning (FOA-MAP)

Firefly meta-heuristic algorithm is powerful in local search. The algorithm follows the peculiar characteristics of the fireflies. Some of the flashing characteristics of the fireflies [44] were idealized with the following three rules:

1. All fireflies are unisex, so that one firefly is attracted to other fireflies regardless of their sex.
2. Attractiveness is proportional to their brightness and thus for any two flashing fireflies, the less bright one will move toward the brighter one. Attractiveness is proportional to their brightness and they both decrease as their distance increases. If there are no brighter fireflies than a particular firefly, it will move randomly in the space.
3. The brightness of a firefly is somehow related with the analytical form of the cost function. The brightness of a firefly is determined by the landscape of the objective function, which is to be optimized.

The steps in finding the location of the sensors using FOA-MAP Algorithm are as follows:

1. The results of MAP-M&N algorithm, giving the approximate solution of the location of each sensor at each specified time

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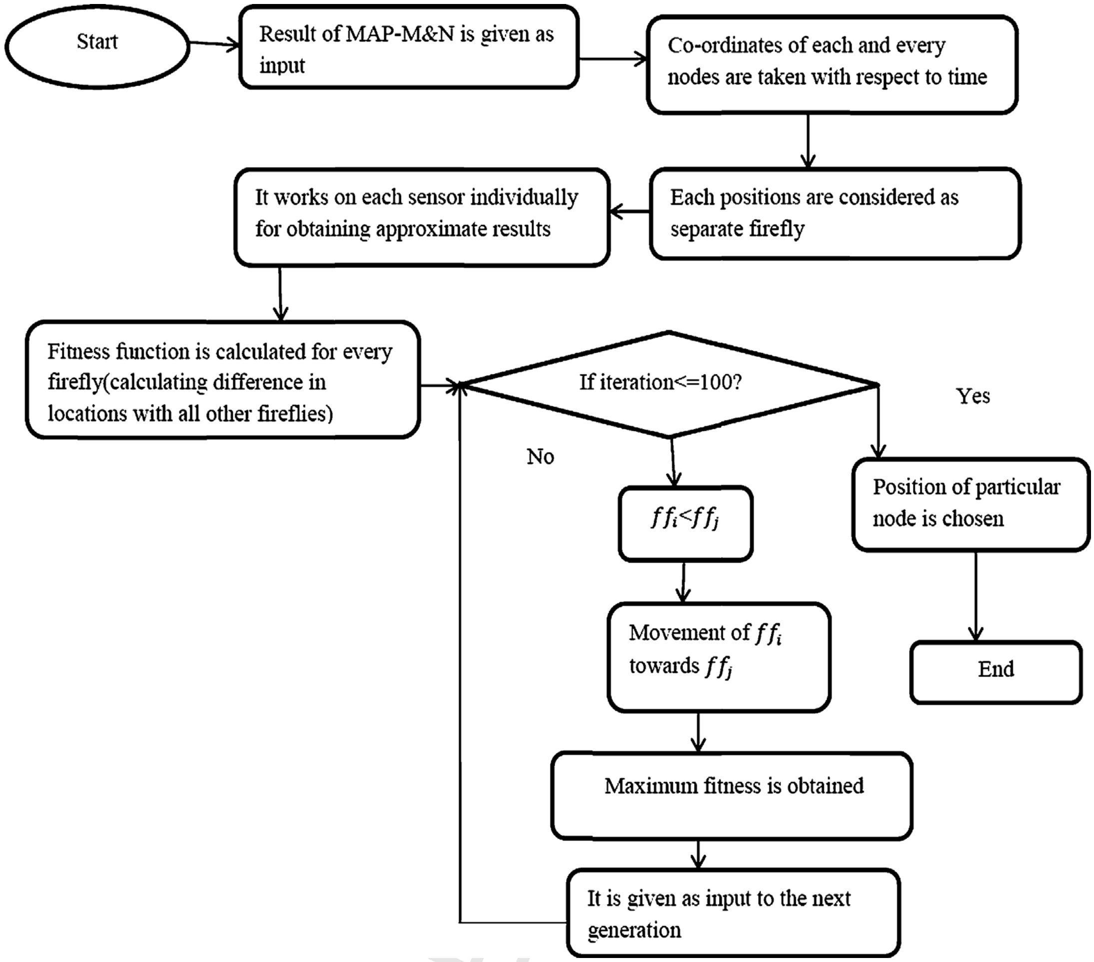

Fig. 4. Flowchart for localization steps in Firefly Optimization Algorithm with Mobile Anchor Positioning (FOA-MAP).

instance is given as the input to the post optimization algorithm namely, Firefly Optimization Algorithm (FOA).

2. Let each node's (*x*,*y*) co-ordinate at different instances of time be (x_1, y_1), (x_2, y_2), ... (x_n, y_n) where n denotes the number of sensor nodes. Each of these positions is considered as a separate firefly. Hence, producing as much of fireflies in the approximate positions found at regular intervals.
3. The firefly algorithm works on each of the sensor individually for obtaining an approximately accurate location of it. Each firefly represents the approximate position of that particular sensor.
4. In each generation, the fitness is calculated for every firefly. Fitness is determined by calculating the difference in location with all the other fireflies.
5. In every generation, each of the fireflies is considered at a time and being compared to all the other fireflies for their fitness.
6. Let the considered firefly be ff_i. If the fitness ff_i is less than that of the firefly being compared to (ff_j), then ff_i moves toward that firefly ff_j.
7. Movement of ff_i toward ff_j varies according to the formula as listed in Eqs. (7) and (8):

$$x_i = x_i + \beta_o e^{-\gamma r_{ij}^2}(x_i - x_j) + \alpha \varepsilon_j \quad (7)$$

where r_{ij} gives the Cartesian distance between ff_i and ff_j which is defined as,

$$r_{ij} = ||ff_i - ff_j|| \quad (8)$$

8. Each of the fireflies undergoes this process and finally the firefly with maximum fitness is chosen and carried over to the next generation.
9. This position is given as the input to the next generation, fireflies are produced randomly and the process is continued until the termination criterion is being met.
   (a) Termination criteria = maximum iterations or profit value.
   (b) Maximum iteration = arbitrarily chosen as 100.
   (c) Profit value = minimum difference in values (10 cm) obtained in the current and the previous rounds.
10. Thus firefly with maximum fitness in the last generation is chosen as the position for that particular node.

The flowchart in Fig. 4 below portrays the localization steps followed using Firefly Optimization Algorithm with MAP (FOA-MAP).

4. Experimental results

In order to compare the performance of three proposed approaches namely, BOA-MAP, MCS-MAP and FOA-MAP in minimizing the localization error is analyzed by simultaneously running in the NS-2 simulator. The simulation settings mentioned in Table 1 have been maintained for all these experiments.

Ad hoc on-demand distance vector (AODV) routing protocol is used especially for broadcasting messages (Hello Packets) during localization and it does not concentrate on routing process in this work. Proposed localization algorithms sits on the application layer since after performing location estimation of the sensor nodes,

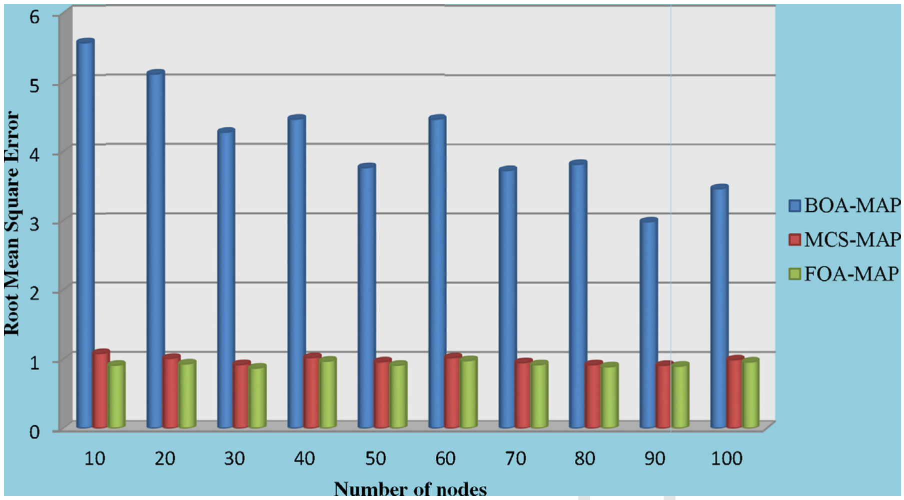

Fig. 5. Graph for comparing RMSE in BOA-MAP, MCS-MAP and FOA-MAP approaches.

Table 1
Simulation settings.

Parameter description	Value
Area of the sensing field	1000 m × 1000 m
Number of sensor nodes	100
Number of mobile anchors	3
Speed of mobile anchors	100 m/s
Time interval between successive anchors	1 s
Execution time	500 s
Transmission range	250 m
Routing protocol	AODV
MAC protocol	IEEE 802.11
Number of generations	10–100

Table 2
RMSE calculation for BOA-MAP, MCS-MAP and FOA-MAP approaches.

No. of nodes	RMSE value obtained for BOA-MAP	RMSE value obtained for MCS-MAP	RMSE value obtained for FOA-MAP
10	5.57	1.08	0.91
20	5.11	1.01	0.93
30	4.27	0.92	0.87
40	4.46	1.02	0.97
50	3.76	0.96	0.91
60	4.46	1.02	0.98
70	3.72	0.95	0.92
80	3.81	0.92	0.89
90	2.98	0.91	0.90
100	3.46	0.99	0.96

it is suitable for applications such as environmental monitoring, weather forecasting, target tracking, etc.

The localization accuracy has been measured based on the minimization in positional error. Root mean square error (RMSE), which is calculated using the formula given in Eq. (9):

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}[x_{act(i)} - x_{obt(i)}]^2 + [y_{act(i)} - y_{obt(i)}]^2}{N}} \tag{9}$$

where $x_{act(i)}, y_{act(i)}$ represent the actual values of x and y coordinates of the sensor nodes, $x_{obt(i)}$, $y_{obt(i)}$ represent the obtained values of x and y coordinates of the sensor nodes and N represents the total number of localized sensor nodes. Table 2 shows the simulation results only after performing ten trials and by taking average of those values, the results have been generalized from that perspective.

From Table 2, it can be observed that the RMSE value drastically reduces while applying FOA-MAP approach when compared to applying BOA-MAP and MCS-MAP approaches. This observation is graphically represented in Fig. 5, where x-axis represents the number of nodes and y-axis corresponds to RMSE value of the sensors. The observation is that there is an increase in RMSE value for the proposed approaches corresponding to 60 nodes when compared to 50 and 70 nodes scenario because the sensor nodes are randomly deployed and every time when the simulator is run for a new trial, the nodes are placed randomly at new positions and localization is performed on them. This can be inferred from Table 2.

5. Conclusions and scope for future research

In this paper certain meta-heuristic approaches, specifically, Bat Optimization, Modified Cuckoo Search and Firefly Optimization have been used to estimate localization information of the nodes in a WSN. The initial solution for these approaches has been taken from the standard range-free localization mechanism namely Mobile Anchor Positioning (MAP) method, which does not involve the usage of any hardware. As MAP method does not give fine-grained accuracy in localization, meta-heuristic approaches are applied on the results of MAP. The FOA-MAP algorithm applied over MAP has significantly reduced the localization error. From the simulation results obtained using NS-2, by using the proposed FOA-MAP approach, there was a drastic reduction in the localization error. With regard to 100 nodes scenario on an average, Firefly Optimization Algorithm with Mobile anchor positioning (FOA-MAP) has reduced the RMSE based localization error by 8.08% when compared to MCS-MAP algorithm. FOA-MAP approach seems to bring down the RMSE based localization error by 72.25% when compared to BOA-MAP algorithm.

Thus, it can be concluded that FOA-MAP meta-heuristic optimization approach is better than using MCS-MAP and BOA-MAP optimization algorithms. In addition, hybridization of optimization such as Genetic Algorithm combined with Firefly can also be applied to further reduce the localization error. The localization error of the new hybrid Firefly algorithm could be compared with the standard Firefly algorithm (FOA-MAP) in order to validate its performance.

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