A localization algorithm using Reliable Anchor Pair selection and Jaya Algorithm for Wireless Sensor Networks

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Research Article

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A localization algorithm using Reliable Anchor Pair selection and Jaya Algorithm for Wireless Sensor Networks

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Abstract

A node localization algorithm using the Jaya algorithm (JA) and range-free method of reliable anchor pair (RAP) selection approach is proposed to determine the position of target nodes or unknown devices in isotropic, O-shaped, and S-shaped anisotropic wireless sensor networks (WSNs). The reliable anchor selection method separates anchor nodes into prime anchor node pairs, subprime anchor node pairs, and unreachable anchor node pairs to determine the distance between anchor node pairs and target nodes. The nature-inspired Jaya algorithm is used to predict the position of the target node. The presented work is compared with the existing localization methods, including DV(Distance Vector)-maxHop, PSO (Particle Swarm Optimization), and QSSA (Quantized Salp Swarm Algorithm) based localization algorithms. The proposed approach increases localization accuracy regarding the number of anchor nodes and node density. The proposed algorithm also looks at how the degree of irregularity and computation time affect the performance.

Keywords: Anisotropic, Isotropic, Jaya, Localization, PSO, QSSA, Wireless Sensor Networks.

1 Introduction

A WSN typically consists of many sensor nodes to continually monitor, detect, and gather data from various environments or objects. The Wireless Sensor Network (WSN) is becoming increasingly essential on the Internet of Things[1] due to its ease of setup, intelligence, reliability, and energy efficiency. Due to their short transmission ranges, sensor nodes usually cannot communicate directly with a base station, so they choose multi-hop communication. On the other hand, sensing data can be rendered useless if the location of the data collection node is unknown, making localization a defining issue in the WSN field [2]. Therefore, many of the proposed localization methods in the literature address the node localization problem [3]. With the support of known location-based anchor nodes, each localization technique is used to locate the location of target nodes whose location is unknown.

The localization algorithms are utilized in various real-life applications such as in industrial domain [4] to detect inventory stocks, in underwater areas [5] to localize and detect sensor nodes, and for outdoor adventures [6]. The node localization algorithms are designed with the help of various types of nature-inspired algorithms such as genetic algorithm [7], salp swarm algorithm [8], and many more [9] are used to solve node localization problems in isotropic WSNs. The anisotropic WSNs suffer from localization problems, and these networks are utilized in real-life applications [10]. The localization algorithms designed to solve anisotropic WSNs localization problems are generally based on hop-based range free distance measurement [11] method and multilateration approach of location calculation [11, 12].

Several node localization algorithms are designed using nature-inspired algorithms for isotropic WSNs to solve the node localization problem [13], while few nature-inspired algorithms are utilized in anisotropic WSNs[14].

This article proposes a node localization strategy for isotropic and anisotropic wireless sensor networks that use the nature-inspired algorithm and range-free approach to solve the problem. The proposed node localization algorithm is based on the Jaya algorithm [15], which was a recently developed nature-inspired algorithm. The distance between the target and anchor nodes is calculated using a reliable anchor selection strategy [16] based on some geometric restrictions.

The rest of the paper is laid out: Section 2 contains related works in node localization using a nature-inspired algorithm. Motivation is covered in section 3 and network modeling. The proposed work, which includes the distance estimation method and the node localization algorithm, is described in section 4. Section 5 presents simulated results and their analysis for various parameters. The study's conclusion and future possibilities for localization in isotropic and anisotropic WSNs are presented in section 6.

2 Related Works

Recently, many node localization algorithms have been presented to solve the node localization problem in the isotropic network. The research interest is moving towards the anisotropic WSNs because such networks are prevalent in the real world. Anisotropic networks are affected by various issues, including non-uniform sensor node distribution, uneven regions, and so on. The localization algorithm in [17] was built using the hop-based range free distance method and trilateration method for target node position estimation in uniform and non-uniform network scenarios. In [18] and [19], the node localization algorithms are presented using an improved DV-Hop-based range-free algorithm for distance estimation. The former uses a runner-root algorithm and later uses a teaching learning-based optimization algorithm for location estimation in WSNs. In [18] and [19] both, the localization error results are compared with the genetic and PSO algorithm-based DV-hop method for different transmission ranges, anchor nodes, and irregularity factors.

The DV-maxHop-based distance estimation method and the multilateration location estimation method are proposed in [11] to improve location accuracy in O, C, and S-shaped anisotropic network topology. To improve the distance estimation between anchor and target nodes, a reliable anchor selection strategy [16],[20–23] is utilized for designing of node localization algorithm. The reliable anchor pair selection strategy provides better distance estimation, and hence it helps in improving localization accuracy in WSNs. In [20], the node localization algorithm is designed using reliable anchor pair selection and multilateration method for location estimation of target nodes in O-shaped AWSNs. In [21], a triangular rule-based reliable anchor selection strategy and multilateration method are used to estimate target nodes' location coordinates in O, C-shaped, and regular-shaped WSNs.

The node localization algorithm presented in papers [22] and [23] uses a reliable anchor selection strategy for distance estimation. The former uses the PSO algorithm and later uses the QSSA algorithm for the location estimation of target nodes. Another localization algorithm designed using Harris hawk optimization(HHO) and area minimization in addition to hop-based distance estimation is proposed in [14]. The node localization technique [13] using a range-based approach and nature-inspired PSO, HPSO (Hybrid PSO), biogeography-based optimization (BBO), and the Firefly algorithm is proposed to acquire the location of moving target nodes. In [24], the principle of fuzzy logic and nature-inspired algorithms are used to increase the location accuracy of nodes in a 3D environment. In terms of coverage, scalability, and location accuracy, this presented node localization technique based on invasive weed and bacterial foraging optimization algorithm outperform the centroid and weighted centroid methods.

The localization algorithms present in [25] and [26] are useful for three-dimensional scenarios. The former uses the concept of centroid, fuzzy logic, HPSO, and BBO algorithms to localize nodes. Later one proposes a range reduction-based localization algorithm in addition to the multilateration method, followed by a least-square analysis. In [27], the Ansuper localization algorithm is proposed, consisting of friendly and unfriendly anchor nodes to estimate distance. The localization algorithms designed using nature-inspired algorithms [14], [22, 23, 25] and provide better localization accuracy for target nodes compared to geometric-based methods such as trilateration and multi-lateration [20],[26]. New localization algorithms can be proposed to estimate location coordinates in anisotropic WSNs after seeing the benefits of nature-inspired algorithms and range-free distance estimation methods based on a reliable anchor selection strategy.

3 Motivation and Network Modelling

In isotropic wireless sensor networks (WSNs), nature-inspired and geometrical methods produce good results for node localization problems, but their accuracies are significantly lowered in anisotropic wireless sensor networks (AWSNs). Isotropic networks are those that do not have any impediments. AWSNs are affected by a variety of impediments as well as other environmental conditions.

3.1 Motivation

The AWSN scenario is shown in Fig. 1, where obstacles prevent the shortest pathways between the target node and anchor nodes from being straight. The anchor nodes in Fig. 1 are represented by a star symbol in red, the target nodes by a circle symbol in blue, and the obstacle by a rectangle. The presence of obstacles causes errors in the location estimation of target nodes because of overestimated distance during the hop count measurements between the nodes. In Fig. 1, the target node t_8 communicates with the anchor node a_1 in the seven hops. If the rectangular obstacle is not present, the actual hop count must be less than seven. Because of this obstacle, the distance from t_8 to a_1 is overestimated, resulting in localization error. This problem is solved in several algorithms given in the related work section.

The localization issues of AWSNs can still be solved by future localization algorithms to improve the target node's localization accuracy, considering their significance to developing knowledge and experience in this field.

3.2 Network Modelling

In this paper, we determine the locations of randomly placed target nodes in isotropic and anisotropic wireless sensor networks. Target node positions are determined by using the anchor nodes, which are already aware of their locations. N anchor nodes and M target nodes are present in the WSN, and the deployment area of nodes = L x L. The concept of node density is used for the simulation analysis and represented as (μ) and defined by Eq. (1):

$$\mu = \frac{\text{Total Number of Nodes}}{\text{Deployment Area}} \tag{1}$$

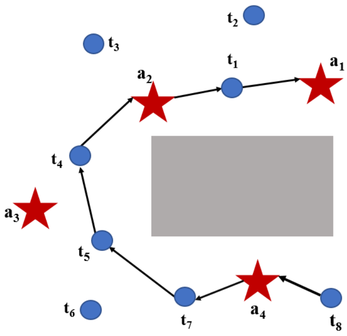


Fig. 1: Motivation scenario for anisotropic networks

The communication radius (Rc) of the anchor and target nodes is the same, and all nodes communicate directly. A practical irregular radio model [26] is utilized to represent the extent of irregularity and noise in distance estimation between the nodes. The maximum communication range variation per unit degree shift in the direction of propagation is defined as the *doi* (degree of irregularity) and calculated from an irregular radio model. The *doi* is measured in terms of the probability, which means its value is $0 \leq doi \leq 1$. This probability is denoted by $P(d)$ [22] to establish the communication between the two nodes having distance 'd' and given by Eq. (2):

$$P(d) = \begin{cases} 1, & \frac{d}{R_c} < 1 - doi \\ \frac{1}{2doi}(\frac{d}{R_c} - 1) + 0.5, & (1 - doi) \leq \frac{d}{R_c} \leq (1 + doi) \\ 0, & \frac{d}{R_c} > 1 + doi \end{cases} \tag{2}$$

4 PROPOSED WORK

The proposed LRAPJA (Localization using Reliable Anchor Pair selection based Jaya Algorithm) node localization algorithm is divided into two phases: distance estimation phase using a reliable anchor pair selection method based on a hop count range free scheme and position determination phase utilizing a nature-inspired Jaya algorithm. For estimating the distance between a reliable anchor node pair and a selected target node, we assume that n^{th} and p^{th} anchor nodes form a reliable anchor pair. The hop count and coordinates are the only datasets sent by the n^{th} anchor node, and this information is received at the m^{th} target node. The estimated distance is given by Eq. (3):

$$\tilde{d_{mn}} = \tilde{d}.h_{mn} \tag{3}$$

where, d_{mn}= distance between the m^{th} target node and n^{th} anchor node, h_{mn}= hop count, $\tilde{d}$= predefined average hop size

The observed hop count value is altered by various environmental disturbances, such as obstructions, holes/cavities, irregular radio propagation patterns, and node distribution. For AWSNs, these factors are known as anisotropic factors. These factors result in a distance estimation error, and [23] introduces a control parameter to improve distance estimation and reduce the localization error. This metric is affected by network factors such as node density, network length, and the minimum number of anchor nodes. Each target node selects a set of reliable anchors to aid in exact distance calculation with the control parameter as a restriction. The hop-constraint technique enhances localization accuracy and reduces the number of communications between neighbors and energy consumption.

4.1 Distance estimation using reliable anchor pair selection method

The target nodes use the reliable anchor pair selection (RAPS) [16] method to determine their distances from the reliable anchor pair nodes to provide an improved location estimate and avoid the problem depicted in Fig.1 for anisotropic WSNs. This strategy uses a geometrical approach to create a minimal possible region for the target nodes to determine their placement correctly. h_{mn} and h_{mp} are the hop counts calculated at the target node 'm' from the anchor node pairs 'n' and 'p'. h_{np} is the hop count between the anchor pairs, and it should be smaller than the total of h_{mn} and h_{mp}.

The average hop progress or reliability [16] (A_h or R_m^{np}) of anchor pairs observed at target node 'm' is given in Eq. (4):

$$A_h \text{ or } R_m^{np} = \frac{d_{np}}{h_{mn} + h_{mp}} \tag{4}$$

The hop counts between anchor pairs and target nodes and the distance between them influence the anchor pairs' reliability. Reliability is defined as a metric for determining the degree of hazard of routing paths. Suppose target node 'm' calculates the distance from anchor node 'n'. In that case, anchor 'n' makes the anchor pairs with $(N - 1)$ anchor nodes and checks the reliability of all the anchor pairs using Eq. (4), and the highest reliable anchor pairs selected for distance estimation. This process follows with the remaining target nodes and anchor nodes to choose a reliable anchor pair. Depending on the hop progress, a different set of anchor pairs are formed: prime, sub-prime, and unreachable anchor node pairs. These sets of anchor pairs can be analyzed based on the geometric relationship. The geometric relationship between prime anchor node pairs and the target node is shown in Fig. 2 to estimate the distance.

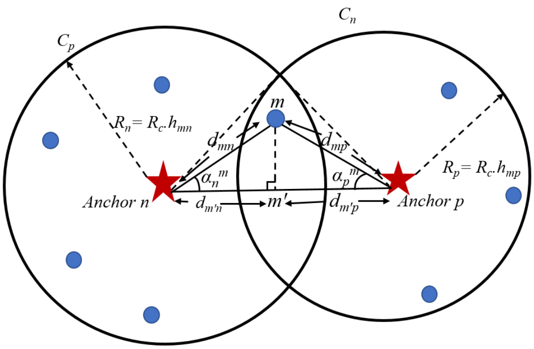


Fig. 2: Geometric approximation of distance estimation between prime anchor node pairs and target node

4.1.1 Prime anchor node pairs

The anchor nodes 'n' and 'p' formed the prime anchor node pair with target node 'm' if satisfies the conditions given in Eqs. (5) and (6) given below:

$$d_{np} > R_c.h_{mn}, \text{ and } d_{np} > R_c.h_{mp} \tag{5}$$

$$-1 \leq \frac{(R_c.h_{mn})^2 + {d_{np}}^2 - (R_c.h_{mp})^2}{2R_c.h_{mn}.d_{np}} \leq 1 \tag{6}$$

Generally, the prime anchor node pairs are subjected to two requirements given below:

1. The two anchor nodes are both positioned outside each other's most significant potential coverage area, which is explained in Eq. (5).

2. The anchors' maximum possible coverage regions must be overlapped, which may be estimated using cosine law and explained in Eq. (6). Fig. 2 depicts an example of a prime anchor node pair and its geometric relation with the target node to estimate the distance between them analyzed using Fig.3.

From Fig.2 and 3, the actual distance between the anchors 'n' and 'p' and target node 'm' is, $d_{mn} = d_{m'n}/Cos(\alpha_n^m)$ and $d_{mp} = d_{m'p}/Cos(\alpha_p^m)$ respectively. The estimated distance from the target node 'm' to anchor nodes 'n' and 'p' are obtained using Eqs. (7) and (8) given below as:

$$\tilde{d_{mn}} = \int_0^{\alpha_n} p_{\alpha_n^m(\alpha)} \frac{R_m^{np}.h_{mn}}{Cos\alpha}\, d\alpha, \text{ and} \tag{7}$$

$$\tilde{d_{mp}} = \int_0^{\alpha_p} p_{\alpha_p^m(\alpha)} \frac{R_m^{np}.h_{mp}}{Cos\alpha}\, d\alpha \tag{8}$$

where,

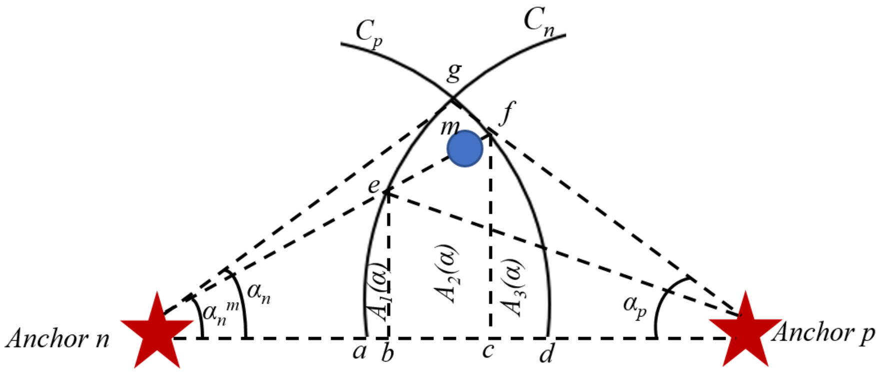


Fig. 3: Geometric approximation for derivation of $f_{\alpha_n^m(\alpha)}$

- α_n^m and α_p^m are random variables as the m^{th} target nodes' location obeys a uniform distribution in the monitoring region and represents a angle between l_{nm} and l_{np} and l_{pm} and l_{np}, line segments respectively.
- $p_{\alpha_n^m(\alpha)}$ and $p_{\alpha_p^m(\alpha)}$ denotes the probability density of α_n^m and α_p^m respectively.

To find out the probability density function (pdf) of α_n^m and α_p^m, the cumulative distribution function (CDF), $f_{\alpha_n^m(\alpha)}$ and $f_{\alpha_p^m(\alpha)}$ are required. The estimated distance between anchor node 'n' and target node 'm' is determined below, and a similar procedure is applied for anchor node 'p'. From Fig. 3, it shows that target node m lies in the area A_{adfe} and the $f_{\alpha_n^m(\alpha)}$ is calculated as:

$$\begin{aligned} f_{\alpha_n^m(\alpha)} &= P(\alpha_n^m \leq \alpha) \\ &= P(\text{node } m \text{ is located within } A_{adfe}) \end{aligned} \tag{9}$$

The area enclosed by A_{adfe} is formed by the summation of $A_1(\alpha)$, $A_2(\alpha)$, and $A_3(\alpha)$, hence Eq. (9) can be written as:

$$f_{\alpha_n^m(\alpha)} = \frac{A_{adfe}}{A_{agd}} = \frac{A_1(\alpha) + A_2(\alpha) + A_3(\alpha)}{A_{agd}} \tag{10}$$

The area $A_1(\alpha)$ is calculated using area of sector (pea), and area of triangle $\triangle peb$, and given as;

$$\begin{aligned} A_1(\alpha) &= A_{\text{area of sector}(pea)} - A_{\triangle peb} \\ &= 0.5R_p^2 \sin^{-1}(\frac{d_{ne}\sin\alpha}{R_p}) - 0.5d_{ne}\sin\alpha(d_{np} - d_{ne}\cos\alpha) \end{aligned} \tag{11}$$

where $d_{ne} = d_{np}\cos\alpha - \sqrt{d_{np}^2\cos^2\alpha - (d_{np}^2 - R_p^2)}$ and $R_p = R_c h_{mp}$ and it expresses the maximum possible transmission range of anchor node 'p'.

The area $A_2(\alpha)$ is found out using the area of the triangles, $\triangle nfc$, and $\triangle neb$ and given as:

$$\begin{aligned} A_2(\alpha) &= A_{\triangle nfc} - A_{\triangle neb} \\ &= 0.5(\sin\alpha)\ (\cos\alpha)(R_n^2 - d_{ne}^2) \end{aligned} \tag{12}$$

Similar to the area of $A_1(\alpha)$, the area of $A_3(\alpha)$ is obtained using area of sector (nfd) and area of triangle, $\triangle nfc$ and given as:

$$\begin{aligned} A_3(\alpha) &= A_{\text{area of sector}(nfd)} - A_{\triangle nfc} \\ &= 0.5R_n^2(\alpha - (\cos\alpha)(\sin\alpha)) \end{aligned} \tag{13}$$

The area A_{agd} can be obtained using the addition of sector areas (ngd) and (pga) while subtracting the area of bigger triangle $\triangle ngp$ using heron's area formula, and given as:

$$A_{agd} = 0.5R_n^2\alpha_{gnp} + 0.5R_p^2\alpha_{gpn} - \sqrt{s(s-d_{np}).(s-R_n).(s-R_p)} \tag{14}$$

Now, using above equations, the pdf of α_n^m is given as:

$$\begin{aligned} p_{\alpha_n^m(\alpha)} &= \frac{\partial f_{\alpha_n^m}(\alpha)}{\partial\alpha} \\ &= \frac{2d_{np}(2R_nR_p + 2d_{np}^2\sin^2\alpha)}{C\sqrt{(d_{np}^2 + \sec^2\alpha(R_p^2 - d_{np}^2))}} - \frac{2d_{np}^2\cos(2\alpha)}{C} \end{aligned} \tag{15}$$

where $R_p = R_c h_{mp}$, $R_n = R_c h_{mn}$, circles $C_n$and C_p, and their intersection area determine C, which is constant. The value of C is given as follows:

$$\begin{aligned} C = 2R_n^2\cos^{-1}\left(\frac{d_{np}^2 + R_n^2 - R_p^2}{2d_{np}R_n}\right) + 2R_p^2\cos^{-1}\left(\frac{d_{np}^2 + R_p^2 - R_n^2}{2d_{np}R_p}\right) \\ -\sqrt{(R_n + R_p - d_{np})(R_n - R_p + d_{np})}.\sqrt{(R_p - R_n + d_{np})(R_n + R_p + d_{np})} \end{aligned} \tag{16}$$

So, now using Eqs. (7), (15), and (16), the estimated distance between anchor node 'n' and target node 'm' can be acquired. Similarly, it is possible to get the estimated distance between the anchor node 'p' and the target node 'm' using Eq. (8).

4.1.2 Sub-prime anchor node pairs

These are the ones in which one and only one anchor are placed inside the other anchor's maximum possible transmission range. Equations 7 and 8 can not be utilized for sub-prime anchor node pairs because the relationship shown in Fig.2 is subsided.
If the following conditions are met, the anchor node pairs are referred to as sub-prime anchor node pairs:

1. The maximum possible coverage areas must be partially crossed.

2. Only one anchor node is present inside the other anchor node's possible coverage area.

The sub-prime anchor node pairs representation is shown in Fig.4, in which target node 'm' and anchor node 'p' are located within the overlapped region and the distance between them can be calculated as:

$$\tilde{d_{mn}} = \frac{d_{np}}{h_{np}} h_{mn}, \text{if } d_{np} < h_{mn} R_c \text{ and } d_{np} > h_{mp} R_c \tag{17}$$

Similarly, the estimated distance between target node 'm' and anchor node 'p' is:

$$\tilde{d_{mp}} = \frac{d_{np}}{h_{np}} h_{mp}, \text{if } d_{np} < h_{mp} R_c \text{ and } d_{np} > h_{mn} R_c \tag{18}$$

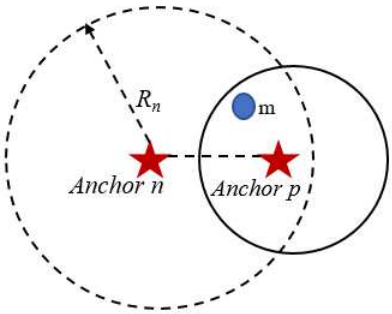


Fig. 4: The subprime anchor node pairs

4.1.3 Unreachable anchor node pairs

The anchor node pairs that are not prime and sub-prime are called unreachable anchor node pairs. These types of pairs can not provide reliable information, and this is because of the degree of irregularity of the radiation pattern.

4.2 Location Determination

In this work, the target nodes are located using a nature-inspired algorithm once the distance between the target and anchor nodes has been determined using a reliable anchor selection strategy. This work utilizes a nature-inspired algorithm named Jaya algorithm (JA)[15]. The JA is used to solve node localization problems because it is a parameter-free and less complex algorithm. It also provides better results in other fields like power maximization[28], single and multi-loop distribution systems[29] etc.

4.2.1 Jaya Algorithm

Rao designed the Jaya algorithm in 2016 to handle both constrained and unconstrained optimization functions. It is significantly simpler to implement this algorithm because it only has one phase. Jaya means "victory" in Sanskrit. This approach uses a population-based metaheuristic that has evolutionary and Swarms intelligence characteristics. It is founded on the behavior of the "survival of the fittest" idea [30]. "The search process of the Jaya algorithm aims to get closer to success by finding the best global solutions and avoiding failure by avoiding the worst choices"[30]. The properties of evolutionary algorithms and swarm-based intelligence are combined in this algorithm.

Let the objective function ψ(x) is to be minimized or maximized according to the problem. Assume that the number of design variables is d and the number of candidate solutions is n (i.e., population size, $k = 1, 2 \ldots, n$) for any iteration t. Let the best candidate acquire the best value of $\psi(x)$ (i.e., $\psi(x)_{best}$) in all candidate solutions, and the worst candidate obtain the worst value of $\psi(x)$ (i.e., $\psi(x)_{worst}$) in all candidate solutions [15]. If the value of the j^{th} variable for the k^{th} candidate during the t^{th} iteration is $X_{(j,k,t)}$, then this value is updated as follows:

$$X^{'}_{(j,k,t)} = X_{(j,k,t)} + q_{(1,j,t)}(X_{(j,best,t)} - \mid X_{(j,k,t)} \mid) - q_{(2,j,t)}(X_{(j,worst,t)} - \mid X_{(j,k,t)} \mid) \tag{19}$$

where, the value of the variable j for the best candidate is $X_{(j,best,t)}$ while the value of the variable j for the worst candidate is $X_{(j,worst,t)}$. $X^{'}_{(j,k,t)}$ is the updated value of $X_{(j,k,t)}$, and $q_{(1,j,t)}$ and $q_{(2,j,t)}$ are two random values in the range [0, 1] for the j^{th} variable during the t^{th}iteration. The term "$q_{(1,j,t)}(X_{(j,best,t)} - \mid X_{(j,k,t)} \mid)$" denotes the solution's tendency to get closer to the best solution [15], whereas the term "$q_{(2,j,t)}(X_{(j,worst,t)} - \mid X_{(j,k,t)} \mid)$" denotes the solution's tendency to avoid the worst [15]. If $X^{'}_{(j,k,t)}$ yields a superior function value, it is accepted. At the end of each iteration, all of the acceptable function values are kept and used as the input for the next iteration. The Jaya algorithm's flow chart is presented in Fig.5.

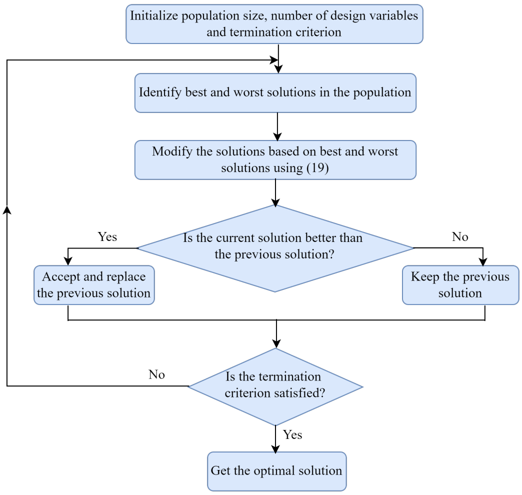


Fig. 5: Flowchart of the Jaya algorithm

4.2.2 Location estimation of target node using Jaya Algorithm

The range-free algorithms generally utilize the hop count-based method for distance calculation. Then trilateration, multilateration, or triangulation [11],[26] methods are used to find the location coordinates of target nodes by applying the least square method. In this work, the nature-inspired Jaya algorithm [15] is used to acquire the coordinates of the target node after determining the distance between reliable anchor pairs and the target node using the reliable anchor selection method described in Part (4.1) of the proposed work. The objective function which is utilized to solve the node localization problem using Jaya algorithm, given as:

$$\psi(\tilde{x_{t_m}}, \tilde{y_{t_m}}) = \Omega_{nm} \sum_{n=1}^{N} \left(\sqrt{(\tilde{x_{t_m}} - x_{a_n})^2 + (\tilde{y_{t_m}} - y_{a_n})^2} - \tilde{d_{nm}}\right) \tag{20}$$

where, $\Omega_{nm} = \frac{\sum_{n=1}^{N} h_{nm}}{h_{nm}}$, and $(\tilde{x_{t_m}}, \tilde{y_{t_m}})$ is the estimated location coordinate of the m^{th} target node, (x_{a_n}, y_{a_n}) is the location coordinate of the n^{th} anchor node.

The proposed LRAPJA algorithm is shown in Algorithm 1. The Jaya algorithm search for the values of $(\tilde{x_{t_m}}, \tilde{y_{t_m}})$ using Eq. (20) in the 2-D search for the isotropic and anisotropic (O and S-shaped) networks that minimizes the localization error.

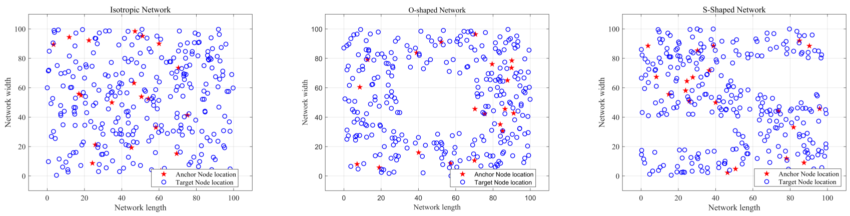
Algorithm 1 Pseudo code of the proposed LRAPJA algorithm.

Initialize parameters
Initialize anchor nodes location information
for every target node **do**
  for $n = 1 : N$ **do**
    for $p = 1 : N$ **do**
      if $n \neq p$ **then**
        calculate reliability using Eq. (4) for all anchor node pairs.
      else reliability= 0
      end if
    end for
    select p with the highest reliability for n to construct the reliable anchor node pair $(n \leftrightarrow p)$.
    if $(n \leftrightarrow p)$ is the prime anchor node pair **then**
      compute $\tilde{d_{mn}}$ and $\tilde{d_{mp}}$ using Eqs. (7) and (8).
    else compute $\tilde{d_{mn}}$ and $\tilde{d_{mp}}$ using Eqs. (17) and (18).
    end if
  end for
  set hop threshold to select reliable anchor node pairs.
  Initialize the position of each population
  Identify the best and worst solutions in the population
  Find out the fitness value of the best candidate population using Eq. (20).
  if Obtained best solutions give the less localization error **then**
    Update the obtained solution using Eq. (19).
  else Maintains the previous solution
  end if
  return the best solution value as the location of target node
end for

5 SIMULATION RESULTS AND ANALYSIS

The presented LRAPJA algorithm's performance is compared with the work presented in the literature. The proposed algorithm is compared to other node localization algorithms such as DV-maxHop [11], PSO-based [22], and QSSA-based [23] for isotropic and anisotropic (O and S-shaped) networks. The network topologies such as Isotropic, O, and S-shaped used to prove the effectiveness of the presented algorithm are shown in Fig. 6a, Fig. 6b, and Fig. 6c, respectively.

The simulation parameters used for different scenarios are given in Table 1 [22],[23].



(a) (b) (c)

Fig. 6: Network topologies a) Isotropic network topology b) O-Shaped network topology c) S-Shaped network topology

Table 1: Simulation parameters for the proposed LRAPJA algorithm

Parameters	**Notation**	**Values**
Network area	S	100 x 100 m^2
Number of anchor nodes	N	20 and 10:5:50
Node Density	μ	0.03 per m^2 and 0.006:0.002:0.03 per m^2
Communication Radius	R_c	20 m
Degree of irregularity	doi	0.05 and 0:0.01:0.1
Population size	P_s	50
Max. no. of iterations	M_I	100
Design Variables	D	2

5.1 Simulation framework

Simulations are performed on the MATLAB software for isotropic and anisotropic networks to illustrate the effectiveness of the proposed algorithm. The normalized localization error is calculated to examine the effectiveness of the proposed node localization algorithm, and its formula is given in Eq. (21):

$$NLE = \frac{\sum_{m=1}^{M} \sqrt{(x_{t_m} - \tilde{x_{t_m}})^2 + (y_{t_m} - \tilde{y_{t_m}})^2)}}{R_c.M} \tag{21}$$

where M is the number of target nodes, (x_{t_m}, y_{t_m}) and $(\tilde{x_{t_m}}, \tilde{y_{t_m}})$ are the actual and estimated coordinates of m^{th} target node respectively, and R_c is the Communication Radius.

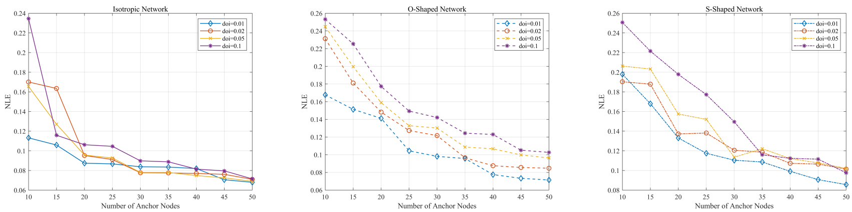
The normalized localization error is calculated for a different set of node density and different numbers of anchor nodes. The effect of the degree of irregularity in communication range is also analyzed for the proposed algorithm to see the impact of environmental disturbances such as shadowing and fading.

5.2 Result Analysis

The performance of the presented algorithm for isotropic and anisotropic (O and S-shaped) networks is evaluated against that of the existing algorithms for varying node density and the number of anchor nodes.

5.2.1 The effect of degree of irregularity on localization

For the proposed node localization algorithm, the effect of *doi* on localization accuracy for several anchor nodes for the isotropic and anisotropic network is shown in Fig. 7. The effect of *doi* for isotropic network, O-shaped anisotropic network, and S-shaped anisotropic network is shown in Fig. 7a, Fig. 7b, Fig. 7c respectively for different values of *doi*=0.01,0.02,0.05 and 0.1 concerning to a varying number of anchor nodes. From Fig. 7, it can be seen that the normalized localization error reduces as the number of anchor nodes increases. The large value of *doi* causes large fluctuations in localization accuracy and results in a large localization error, so a fair value of *doi* =0.05 is taken to compare the localization results concerning the state-of-the-art algorithms for isotropic and O and S-shaped anisotropic networks. The isotropic network has less localization error compared to the anisotropic network, and this is because of environmental disturbances in the network.

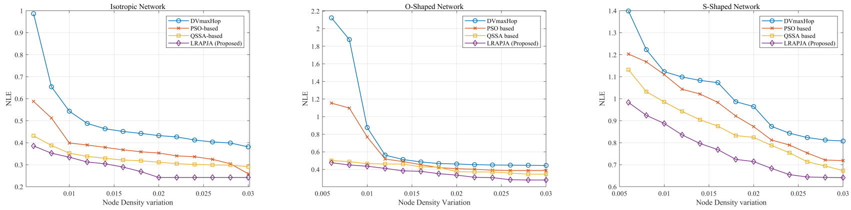


(a) (b) (c)

Fig. 7: The effect of *doi* on localization (a) Isotropic network (b) O-shaped Network (c) S-shaped network

5.2.2 The effect of node density on localization

The effect of node density on localization error is analyzed in this section for isotropic and O and S-shaped anisotropic networks and it is shown in Fig 8a, Fig 8b, and Fig 8c respectively. The value of *doi* = 0.05 and the fixed number of anchor nodes = 20 to see the node density effect. The range of node density $\mu = 0.006\ to\ 0.03$ is taken for analysis for all the networks with an interval of 0.002. The proposed LRAPJA node localization algorithm outperforms the DV-max hop [11], PSO-based [22], and QSSA-based [23] algorithms, as shown in Fig.8. The proposed localization algorithm provides less localization error in isotropic and O-shaped networks compared to the S-shaped network with two types of obstacles. Due to obstacles, localization accuracy decreases, but this network still outperforms other existing algorithms, as shown in Fig 8.

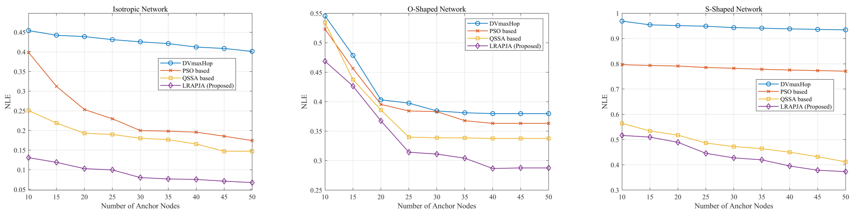


(a) (b) (c)

Fig. 8: The effect of node density on localization (a) Isotropic network (b) O-shaped Network (c) S-shaped network

5.2.3 The effect of anchor nodes on localization

The effect of anchor nodes on localization error is analyzed in this section for isotropic and O and S-shaped anisotropic networks, which are shown in Fig 9a, Fig 9b, and Fig 9c respectively. The value of $doi = 0.05$ and the fixed value of node density, $\mu = 0.03$, are taken to see the effect of a varying number of anchor nodes. The higher value of node density is taken as it signifies more connectivity between the nodes. The range of anchor nodes N is 10 to 50 and is taken for analysis with an interval of five. The proposed LRAPJA node localization algorithm provides better results compare to DV-max hop [11], PSO-based [22] and QSSA-based [23] node localization algorithms for different number of anchor nodes, as shown in Fig.9. The LRAPJA algorithm provides better results as it uses a hop count threshold for selecting reliable anchor pairs in the anisotropic network to increase distance estimation accuracy. Also, for location estimation, it utilizes the Jaya algorithm, which has only one equation for analysis and requires algorithm-specific parameters only.



(a) (b) (c)

Fig. 9: The effect of anchor nodes on localization (a) Isotropic network (b) O-shaped Network (c) S-shaped network

The PSO-based, QSSA-based, and proposed Jaya-based algorithm provides comparable results in comparison to DV-max hop because the former uses reliable anchor pair selection method in addition to the hopping method and all algorithms inspired by nature. In contrast, later, one uses the max hop-based method and the multilateration method, a geometric approach for localization. The proposed LRAPJA node localization algorithm outperforms other algorithms in node density and number of anchor nodes for isotropic and O and S-shaped anisotropic networks.

The average of NLE for the proposed and all other compared algorithms for all the networks is shown in Table 2 and Table 3 for varying node density and number of anchor nodes, respectively.

Table 2: Average of NLE for all the algorithms for node density variation (μ=0.006:0.002:0.03 per m^2, $N = 20$)

Type of Network	DV-maxhop	PSO-based	QSSA-based	LRAPJA (Proposed)
Isotropic network	0.4986	0.3777	0.3294	0.2845
O-shaped network	0.7395	0.5591	0.4157	0.3607
S-shaped network	1.008	0.9321	0.8577	0.7615

Table 3: Average of NLE for all the algorithms for varying number of anchor nodes (μ=0.03 per m^2 , N = 10:5:50)

Type of Network	DV-maxhop	PSO-based	QSSA-based	LRAPJA (Proposed)
Isotropic network	0.4261	0.2386	0.1854	0.0914
O-shaped network	0.4144	0.3999	0.3764	0.3393
S-shaped network	0.9462	0.7829	0.4815	0.4395

Table 2 shows that the proposed algorithm provides 42.94%, 51.22%, and 24.45% improvement compared to the DV-max hop algorithm for node density variation in isotropic, O-shaped, and S-shaped networks, respectively. The results in Table 3 signify an improvement in the proposed algorithm compared to DV-max hop for varying the number of anchor nodes for isotropic, O-shaped, and S-shaped networks are 78.54%, 18.12% and 53.55% respectively.

5.2.4 Computation Time Analysis

Fig. 10 shows the average time required to locate a node in simulations with varying numbers of anchors when the monitored region is 100 x 100 m^2, and the communication range is 20m for both anchor and target nodes. The simulation results indicate that for a node density of 0.03, it takes an average of 46.17% longer to position a node in the network than for a node density of 0.02 because the former distributes anchoring information by the method is more time-consuming.

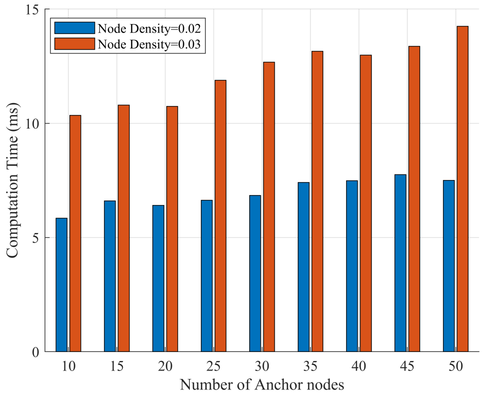


Fig. 10: Computation Time analysis for isotropic and anisotropic network

6 Conclusions

In this paper, the nature-inspired Jaya algorithm is utilized to calculate the location of the target node and the reliable anchor pair selection method for distance estimation between the target node and reliable anchor pair nodes. The Jaya algorithm is less complex and depends only on algorithmic specific parameters. The proposed LRAPJA algorithm calculates the location of target nodes in isotropic and O and S-shaped anisotropic networks. The performance of the LRAPJA algorithm is measured in terms of localization accuracy, degree of irregularity, and computation time. The normalized localization error is calculated for a varying number of anchor nodes and varying node density for *doi*=0.05.The increased number of anchor nodes provides good localization accuracy but makes the algorithm costly. With the increase in node density while keeping the number of anchor nodes are 20, this proposed algorithm outperforms other algorithms for isotropic and anisotropic networks in terms of the localization error.

The results of the proposed algorithm are compared with the existing algorithms such as DV-maxhop[11], PSO-based[22] and QSSA-based [23] node localization algorithm, and it outperforms these existing algorithms. The higher value of the degree of irregularity (*doi*) causes a significant error in localization accuracy; hence to prove the effectiveness of the proposed algorithm, the *doi* value is taken as 0.05. The computation time analysis is also done for the proposed algorithm for different node densities in isotropic and anisotropic networks. The proposed LRAPJA algorithm performs well because it utilizes the reliable anchor pair selection method with a max hop threshold to limit the number of reliable anchor nodes for distance estimation.

Future work will also focus on implementing the proposed algorithm for three-dimensional environments. The energy analysis can also be included.

Other variants of the nature-inspired Jaya algorithm can be designed and used to improve the localization accuracy of target nodes in WSNs.

Data availability statement

This manuscript has no associated data.

Declarations

Conflict of interest The authors declare that they have no conflict of interest in proposed manuscript.

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