Regularized Least Square Multi-hops Localization Algorithm for wireless sensor networks

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Abstract

Multi-hop localization is a an important technique for Wireless Sensor Networks. Location awareness is very crucial for almost existing sensor network applications. However, using Global Positioning System (GPS) receivers to every node is very expensive. Therefore, the Distance Vector-Hop algorithm (DV-Hop) is proposed and very famous for its simplicity and localization accuracy for Wireless Sensor Networks. The cited algorithm uses a small number of anchor nodes, which are equipped with GPS, thus their locations are known, while other nodes estimate their location from the network connectivity information. However, DV-Hop presents some deficiencies and drawbacks in terms of localization accuracy. Therefore, we propose in this paper an improvement of DV-Hop algorithm, called Regularized Least Square DV-Hop Localization Algorithm for multi-hop wireless sensors networks. The proposed solution improves the location accuracy of sensor nodes within their sensing field in both isotropic and anisotropic networks. Simulation results prove that the proposed algorithm outperforms the original DV-Hop algorithm with up to 60%, as well as other related works, in terms of localization accuracy.

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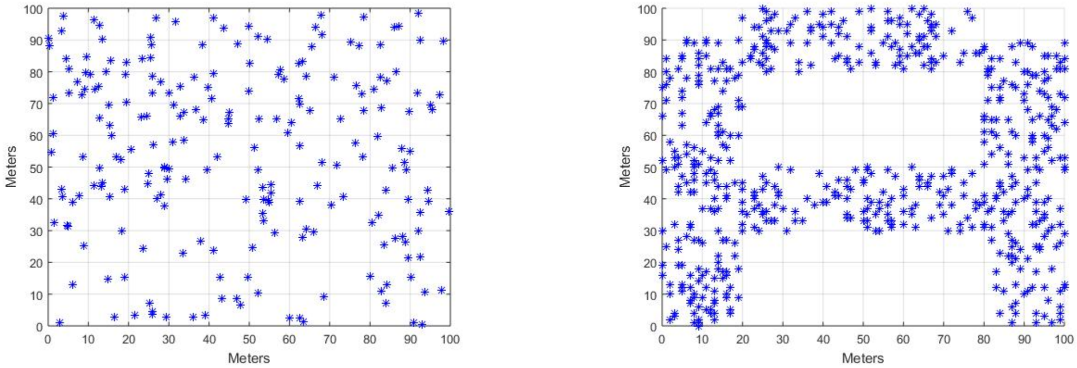
Keywords Multi-hop wireless sensor networks · localization · Distance Vector-Hop algorithm · localization accuracy · Regularized Least Square.

1 Introduction

Nowadays, wireless sensor networks (WSNs) present an important component of cyber-physical systems in internet of things (IoT). Besides, WSNs are considered as one of the hottest research topics under the spotlight worldwide. Moreover, WSNs technology is applied in many fields including military, industry [30], medicine, environmental monitoring [3], and so on [26]. In industrial and commercial WSN applications, several localization techniques were presented to minimize localization error and improve localization accuracy. These localization techniques are mainly classified as range-based and range-free. Regarding wireless sensor nodes, they can be deployed in the isotropic and anisotropic environment, as seen in Fig. 1.

Generally, WSNs are consisting of a set of smart sensor nodes deployed in isolated areas and planned to work in the interested zone. These sensor nodes have several resource constraints such as limited battery power and they did not have a geographic location device (such as GPS). In many Internet of Things (IoT) and Fourth Industrial Revolution (or Industry 4.0) applications, the collected information depends on the locations of sensor nodes. Thus, without accurate positions of sensor nodes, the collected data is of the least importance and produces weak results during the exploitation phase. Therefore, sensor nodes locations are one of the most basic elements in WSNs, which presents a funda-



(a) Isotropic deployment nodes

(b) Anisotropic deployment nodes in A-shaped topology

Fig. 1 Deployment nodes classification

mental key in many wireless applications.

Localization methods in the literature are summarized in [11, 15, 23, 24]. These localization algorithms consist of range-based and range-free methods [24]. Range-based methods are mainly based on the distance or angle metric between sensor nodes. The most used techniques are the Received Signal Strength Indicator (RSSI) [27], Angle of Arrival (AOA) [19], Time of Arrival (TOA) [9], and Time Difference of Arrival (TDOA) [21]. Due to the great interference and the electromagnetic pollution related to the environment, the resulted localization error is comparatively large and there are additional costs for hardware measuring equipment. Unlike rang-based methods, range-free methods, reduce their requirements over sensor node hardware, and have wide advantages in costs and enery consumption. Besides, the localization accuracy resulted from these range-free methods is less touched by environmental agent. Therefore, these methods have become the main research direction. As an example of range-free algorithms, we can cite Centroid algorithm [2], APIT [13], DV-Hop [20], Bounding Box algorithm [12], and Sequence-Based algorithm [32]. These methods are known as connectivity-based algorithms. Traditionally, the popular DV-Hop algorithm, as a range-free technique, uses the Global Positioning System (GPS) [7] and distance vector routing protocol. Besides, it estimates the inter-nodes distances by utilizing the information of the distance vector and network connectivity (multi-hop inter-nodes communication). Therefore, DV-Hop does not demand on the physical measuring unit, and it has good performance in the isotropic networks [22]. The weakness of the DV-Hop algorithm is not trivial, thus optimization tools to calculate the inter nodes distances estimation and several new range-free algorithms, known as improved DV-Hop, are proposed in the literature for tolerating the errors introduced in the distance estimation by the DV-Hop algorithm.

The remainder partitions of this paper are as follows: Section 2 presents some improved localization algorithms of DV-Hop in the literature. Section 3 gives briefly a review of the DV-Hop algorithm for wireless sensor networks. Section 4 describes our proposed regularized least square localization algorithm. Section 5 exhibits the simulation results of the proposed algorithm as well as its performance evaluation. Finally, a conclusion is given in Section 6.

2 Related Works for Improved DV-Hop algorithms

Generally, the popular DV-Hop algorithm suffers from a large localization error and reduced accuracy due to the error introduced by the inter-nodes distance estimation. In fact, several improved DV-Hop localization algorithms have been proposed by scientists to ameliorate the localization accuracy of the original DV-Hop algorithm for wireless sensor networks application. However, in multi-hop based range-free cases, these proposed amelioration methods have some drawbacks in terms of practical application, localization accuracy and calculation complexity [34].

In the two last decades, some improved DV-Hop localization algorithms are developed to optimize the range-free algorithms for the localization process. Indeed, in [29], the authors presented an improved distance vector-Hop localization algorithm (CC-DV-Hop), which exploits the coordinate correction. In fact, the coordinate correction via the DV-Hop gives the pseudo-range error coefficient which improves the length of the average distance per hop. Moreover, the unknown node and the anchor nodes are considered as unknown when obtaining their coordinate correction values which are employed to correct iteratively the localization results of unknown nodes. The results show that CC-DV-Hop has better localization accuracy compared with the original range-free DV-Hop algorithm and other improved algorithms from the literature.

In [25], authors proposed two novel DV-Hop localization algorithms for randomly deployed WSNs, which are the hyperbolic-DV-hop algorithm and the improved weighted centroid DV-hop algorithm (IWC-DV-Hop). The authors used the average HopSizes of all anchors in the network instead of using the average distance per hops of anchor nodes which is near to unknown node. Noting that the use of the global average hop-size of the nearest anchor to an unknown node is a source of large errors and low localization accuracy.

Authors in [16] proposed a Weighted Hyperbolic DV-Hop Positioning Node Localization Algorithm in WSNs. This paper evaluates the performance of multi-hop localization algorithms used in range-free cases, such as DV-Hop, Improved DV-Hop (IDV-Hop) [5], and the Weighted DV-Hop (WDV-Hop) [1]. The authors proposed another localization algorithm combining the WDV-Hop with the weighted hyperbolic localization algorithm scheme, including weights to the correlation matrix of the estimated distances between the unknown node to be localized and the anchor nodes to improve accuracy and precision of localization. The proposed hybrid WDV-Hop yields good accuracy than the other analyzed algorithms due to the correction of the average-distance per-hop included in the algorithm. In [31], a novel strategy for WSN localization problem presented called Reliable Anchor-based Localization algorithm (RAL). The main strategy in this work is to ameliorate the localization accuracy via the elimination of the adverse effect of detoured anchors path by obstacles and use only reliable anchors for the localization process. Each sensor node will choose its own reliable anchor set for localization. The weakness of this approach is that the efficiency of this approach depends on the resultant lookup table, which is computed offline based on the density sensor of the WSN, hop-count, and Degree of Radio Irregularity (DOI) [22] which minimizes radio signal propagation irregularities. Additionally, the algorithm requires some computation effort when compared to DV-Hop. It is often considered that the accuracy amelioration is given essentially based on the strategy of anchor selection and the amelioration of the expected distance between inter-sensor nodes. In the majority of cases, the proposed improved DV-hop localization scheme is compared with some techniques in the literature for isotropic and anisotropic WSN.

Authors in [6] proposed a range-free localization algorithm for anisotropic WSNs, in which the position of the unknown node is properly estimated regarding a new reliable anchor selection strategy that guarantees a good estimation accuraty of the distance.

In [4] the authors proposed a hybrid DV-Hop algorithm using RSSI to estimate distance between neighbor node instead of using the distance per hop generated by the original DV-Hop. Moreover, the algorithm promotes localized nodes to be used as anchors, which permits to support large scale WSN.

3 Review of the DV-Hop Algorithm

Assisted by the anchor position, the fundamental concept of DV-Hop algorithm [20] is to calculate the distances separating unknown nodes and anchor nodes within the sensor network, average Hop-size and then get an estimation of unknown node position via Trilateration or Multilateration method.

The algorithm is consisting of three stages:

Stage 1: The anchor nodes forwards packets to neighboring nodes in the network. An unknown node obtains the minimum hops count of each anchors, and then forwards to the neighboring nodes with incremental hops value.

Stage 2: When every anchor node get other nodes's position information and minimum number of hops, the average distance per-hop (HopSize) can be estimated by using Equation (1).

$$HopSize_i = \frac{\sum_{i \neq j}^{n} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_{i \neq j}^{n} h_{ij}} \tag{1}$$

Where $h_{i,j}$ is the shortest path hop-count between anchor a_i and a_j, and (x_i, y_i) and (x_j, y_j) are the coordinates of a_i and a_j respectively.

We can estimate the distance $d_{i,u}$ between the unknown node u and anchor node a_i using the next formula:

$$d_{i,u} = h_{i,u} \times HopSize_i \tag{2}$$

Stage 3: In accordance with the estimated distance separating the unknown nodes with each anchor nodes, the Trilateration or the Multilateration method is used to compute the position of unknown nodes, as follows:

$$\begin{cases} (x_u - x_1)^2 + (y_u - y_1)^2 = {d_{1,u}}^2 \\ (x_u - x_2)^2 + (y_u - y_2)^2 = {d_{2,u}}^2 \\ . \\ . \\ . \\ (x_u - x_n)^2 + (y_u - y_n)^2 = {d_{n,u}}^2 \end{cases} \quad (3)$$

Where,(x_u, y_u) is the position of unknown node; (x_1, y_1), (x_2, y_2)...(x_n, y_n) are the positions of anchor nodes.

Equation (3) can be simplified to the linear equation (4).

$$AX = B \quad (4)$$

Where $X = \begin{pmatrix} x_u \\ y_u \end{pmatrix}$

$$A = -2 \times \begin{pmatrix} x_1 - x_n & y_1 - y_n \\ x_2 - x_n & y_2 - y_n \\ . & \\ . & \\ . & \\ x_{n-1} - x_n & y_{n-1} - y_n \end{pmatrix}$$

$$B = \begin{pmatrix} d_{1,u}^2 - d_{n,u}^2 - x_1^2 + x_n^2 - y_1^2 + y_n^2 \\ d_{2,u}^2 - d_{n,u}^2 - x_2^2 + x_n^2 - y_2^2 + y_n^2 \\ . \\ . \\ . \\ d_{n-1,u}^2 - d_{n,u}^2 - x_{n-1}^2 + x_n^2 - y_{n-1}^2 + y_n^2 \end{pmatrix}$$

Note that the matrix A encodes the geographical information about the anchor nodes deployment, the B vector gives the information about distances inter-sensor nodes measurements, and X presents the unknown positions of the sensor nodes to be estimated.

Finally, the least square method aims to solve equation (4), as follows, and determines the coordinates of unknown nodes in the network.

$$X = (A^T A)^{-1} A^T B \quad (5)$$

Then, we get: $\begin{cases} x = X(1) \\ y = X(2) \end{cases}$

4 The Proposed Regularized Least Square DV-Hop Localization Algorithm (RLS-DV-Hop)

In this section, we introduce our regularized least square localization algorithm for WSNs, which consists of three steps as follows:

4.1 Step 1: WSN discovery

The first step works like the stage number one of the original DV-Hop, where the minimum hop-count between all nodes is determined. Firstly, the number of hops between the available anchor nodes are determined and presented as a matrix Hca of dimension $na \times na$, where na is the number of anchors. The $Hca(i, j)$ represents the hop-count between anchor a_i and anchor a_j. Moreover, the hop-count between the unknown nodes and anchors are computed and presented as matrix Hcn of dimension $na \times nn$, where na presented the number of unknown nodes.

4.2 Step 2: Hop-size identification and distance estimation

The distance matrix Da of dimension $na \times na$ between anchors is calculated using the following equation: follows:

$$da_{i,j} = \sqrt{(xa_i - xa_j)^2 + (ya_i - ya_j)^2} \quad (6)$$

Where a_i and a_j are two anchor nodes. We suppose that the relation between hop-count Hca in WSN and the distance matrix Da is given by the next linear equation.

$$Hca \cdot \Omega = Da \quad (7)$$

The solution of equation 7 can be given using the least square solution [33]. Then, the obtained solution and the objective function are expressed as follows:

$$\Omega = arg_{\Omega} \;\; min||Hca \times \Omega - Da||^2 \quad (8)$$

where $||.||^2$ is the L_2-norm.
In our approach, we aim to use the Regularized Least Squares (RLS) for solving the least square problem while using regularization to further constrain the resulting solution. In the case of anisotropic WSN, considering the error introduced by inter-nodes distances estimation, we improve the solution based on equality constraint and the generalization performance. The main idea of this approach is to minimize the quadratic localization errors and the Ω vector norm. This proposed

approach can be given by the following objective function:

$$\Omega = arg_{\Omega} \ min||Hca \times \Omega - Da||^2 + \alpha||\Omega||^2 \quad (9)$$

where $||.||^2$ is the L_2-norm, α is a parameter that needs to be adjusted during simulations.
Then, the solution for the above least square problem is:

$$\Omega = Hca^{+} \cdot Da \quad (10)$$

Where

$$Hca^{+} = (Hca^T Hca)^{-1} Hca \quad (11)$$

The Hca^{+} represents the Moore-Penrose generalized inverse matrix [8] of Hca. Therefore, Ω can be expressed as follows:

$$\Omega = (Hca^T \cdot Hca)^{-1} Hca \cdot Da \quad (12)$$

and the generalized Ω solution can be expressed as follows, where Hca and Da between anchors are already calculated:

$$\Omega = (Hca^T Hca + \frac{1}{C} * Id)^{-1} Hca \cdot Da \quad (13)$$

The calculated value of Ω is an identification of the Hop-size of anchors.
where Id is the identity matrix, and C is a constant to be adjusted during the simulation process. The matrix $\frac{1}{C} * Id$ is presented as follows.

$$\frac{1}{C} * Id = \begin{pmatrix} \frac{1}{C} & 0 & 0 & \cdots & 0 \\ 0 & \frac{1}{C} & 0 & \cdots & 0 \\ 0 & 0 & \frac{1}{C} & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 0 & \frac{1}{C} \end{pmatrix}$$

Finally, the matrix of hop-count between the unknown sensor nodes and anchor nodes is known and presented as matrix Hcn with dimensions $nn \times na$, the distance estimation $\hat{Dn}$ between anchors and unknown nodes can be expressed as follows:

$$\hat{Dn} = Hcn \cdot \Omega = Hcn(Hca^T Hca + \frac{Id}{C})^{-1} Hca \cdot Da \quad (14)$$

4.3 Step 3: Nodes localization

We note that the geographical location of the anchor nodes matrix (with dimensions $na \times 2$) noted by Xa and the estimated unknown geographical position of sensor nodes matrix (with dimensions by $nn \times 2$) noted by Xu. We suppose that the relation between distances in wireless sensors network Da and the geographical position matrix Xa is given by the next linear equation:

$$Da \cdot \Psi = Xa \quad (15)$$

The least square solution is given by the following formula:

$$\Psi = Da^{+} \cdot Xa \quad (16)$$

Where $Da^{+} = (Da^T Da)^{-1} Da$.
The expected geographical position of the unknown sensor node can be given as follows:

$$\hat{Xu} = \hat{Dn} \cdot \Psi = \hat{Dn} \cdot (Da^T Da)^{-1} Da \cdot Xa \quad (17)$$

Fig. 2 gives an explanatory graph of the proposed method for nodes localization.

We give here a computation example of our proposed method. We propose a sensor network consisting of anchors $A1, A2, A3$ and $A4$, as well as unknown nodes, including the node UN, designed with red and blue symbols respectively. The sensing area is 20×20 meters as shown in Fig. 10. The communication range of each node is about 10 meters. Anchors are equipped with a GPS module which help them to know their positions in the network as well as their distances and number of hops from each other, noted as Da and Hca, as presented in Table 1 and 2 respectively. We perform all computation of this example using MATLAB 2015a.

Table 1 Minimal hop-count between anchors (Hca).

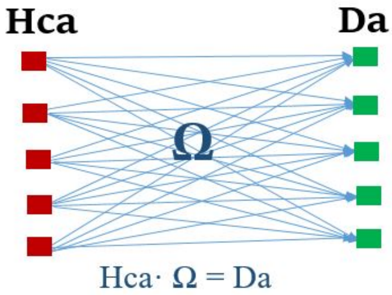
Hop Count	A1	A2	A3	A4
A1	0	4	4	4
A2	4	0	4	4
A3	4	4	0	4
A4	4	4	4	0

Table 2 Real distance between anchors (Da).

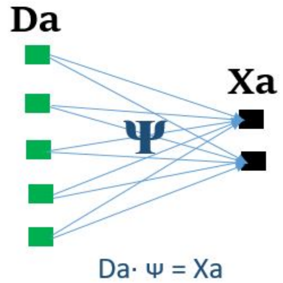
Distance (meters)	A1	A2	A3	A4
A1	0	20	20	28.28
A2	20	0	28.28	20
A3	20	28.28	0	20
A4	28.28	20	20	0

After knownig the matrix of hops Hca and the distance matrix Da between anchors, the value of Ω can be calculated as in Eq. 13. Results are shown in Table 3.

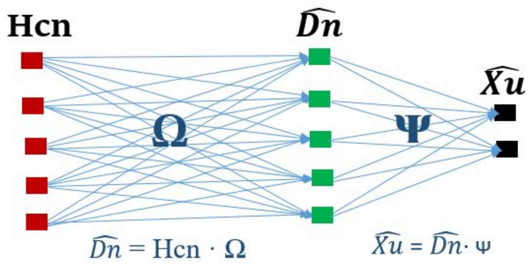
Then, we aim to determine an estimation of the distance, noted as $\hat{Dn}$, that separates the anchor nodes $A1, A2, A3$ and $A4$ with the unknown node UN by Eq. 14. The resulted estimated distance is given in Table 4.



(a) Identification of the Hop-size



(b) Identification of the localization parameters



(c) Localization of unknown nodes

Fig. 2 Proposed localization method

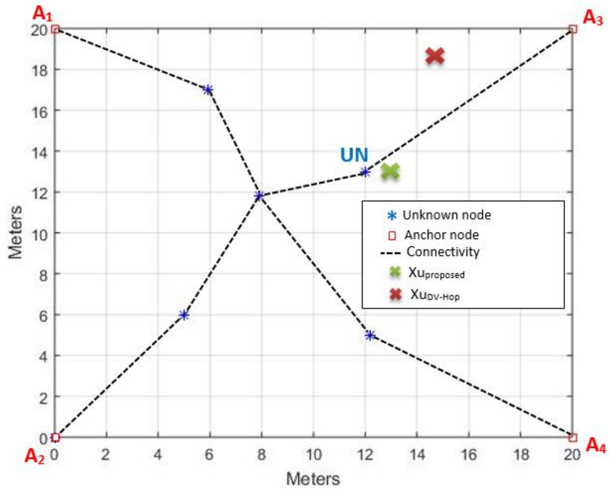


Fig. 3 Localization example

Table 3 Ω.

Ω	**A1**	**A2**	**A3**	**A4**
A1	5.67	0,74	0,74	-1.43
A2	0,74	5,67	-1.43	0,74
A3	0,74	-1.43	5,67	0,74
A4	-1.43	0,74	0,74	5,67

Table 4 Estimated distances between unknown node UN and anchor nodes.

Estimated distance $\hat{D}n$	**A1**	**A2**	**A3**	**A4**
UN	15.69	20.04	5.81	15.69

Finally, in the third step of our proposed technique, the coordinates of the unknown node can be estimated. The hop-count matrix between the unknown sensor nodes and anchor nodes is known and presented as matrix Hcn, then the estimated position Xu of the unknown node UN can be calculated using Eq. (17). Then, the estimated positions calculated by using our proposed algorithm and by the original DV-Hop algorithm are as follows:

Table 5 Estimated position of unknown node UN.

Xu	**Xu(1)**	**Xu(2)**
DV-Hop algorithm	14.32	18.32
Proposed algorithm	13.26	13.26

Table 6 Comparison of the estimation error.

	Accuracy
DV-Hop algorithm	0.59
Proposed algorithm	0.13

As seen in Table 5, the resulted estimated position of UN using the proposed aproach is closer to the real position than that resulted by the DV-Hop. Besides, Table 6 shows the average localization error of the proposed method and that of the DV-Hop. Then, we can conclude that our proposed method aims to good localization performance. In the next section, we will establish an evaluation of the performance of our technique and compare it with the original DV-Hop and other localization schemes from the literature.

5 Performance evaluation

To test the performance of our proposed technique, we simulated it using MATLAB R2015a. The proposed method was evaluated in both isotropic and anisotropic networks. In the meantime, we also compare it with other localization algorithms from the literature including the original DV-hop [20], enhanced Weighted Centroid DV-Hop (EWCL) algorithm [14], Improved Recursive (IR-DV-hop) DV-Hop algorithm [18], the localization algorithm based on the improved DV-Hop and differential evolution (DE) algorithms (DEIDV-HOP) [10] and a multi-objective DV-Hop localization algorithm based on NSGA-II (NSGA-II-DV-Hop) [28]. All of these cited DV-Hop improvements are selected thanks to its good localization accuracy against that of the DV-Hop. Therefore, we perform simulations to prove the highest accuracy of our proposed method in comparison with these cited algorithms. The reported results of all comparisons are the average over 100 trials for better simulation results.

5.1 Localization results

5.1.1 Different topologies of network

In this section, we aim to show the localization results and highlight the localization error of sensor nodes in the network of both the proposed algorithm and the DV-Hop algorithm, in both isotropic and anisotropic networks. For the isotropic environment, sensor nodes are deployed in the sensing field with a random way, while in the other case of deployment, we adopt realistic deployment conditions in which sensor nodes are deployed in a sensing field that holds obstacles, such as buildings, pieces of equipment, etc. In fact, this case may causes anisotropies, sparsity in the sensing network, non-uniform distribution of nodes, and irregular communication patterns. So, we adopt in our simulations two different complex network topologies: C-shaped and A-shaped random topologies. The network size is set to $100 \times 100m^2$. In these network topologies, anchors are placed in the boundary of the sensing field. We set up the parameter α at 0.5, and the parameter C at 2. Network topologies as well as localization results are shown in Fig. 4, Fig. 5 and Fig. 6. We denote the anchor node by a red square and unknown node, which location is to be determined, by a blue symbol $" * "$. All deployed nodes communicate via a radio range of 20 meters. The blue circle indicates the real location of the unknown node and the red straight line marks the error of localization.

One can see from Fig. 4, Fig. 5 and Fig. 6 that the postion estimation error obtained in the DV-Hop algorithm is much higher than that obtained in the proposed algorithm under both the two different topologies. Therefore, We demonstrate from these figures that localization accuracy can be significantly improved in the proposed algorithm for both isotropic and anisotropic wireless sensor networks.

5.1.2 Different distributions of anchors

In this section, we perform simulations by changing the form of anchor deployment in the case of isotropic sensing network. The evaluation of our proposed localization algorithm against DV-Hop algorithm has then proceeded under different anchor deployment schemes: border placement, spiral, and circular distributions which are presented in Fig. 7, Fig. 8, and Fig. 9 respectively. One can see from thess figures that the localization error, presented by the red straight line (as in the previous section), is lower in the case of our proposed method when compared with the DV-Hop for all different anchor placement types. Therefore, our proposed algorithm outperforms in accuracy its counterpart. This further highlights the advantage of our localization technique over the DV-Hop algorithm.

5.2 Comparison of Average Localization Error of RLS-DV-Hop with other localization algorithms

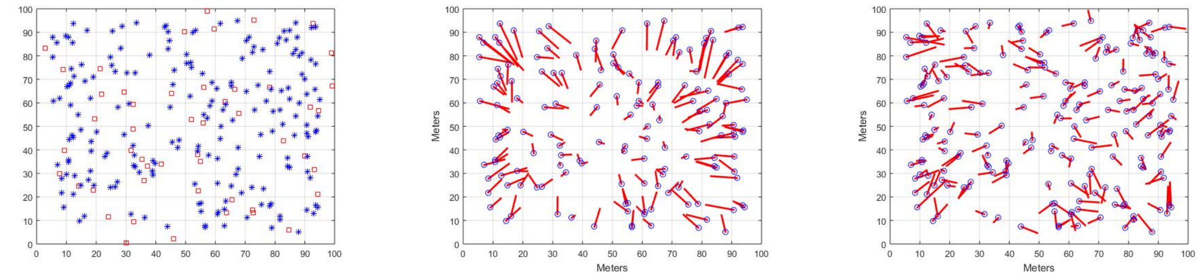
In this section, we conduct the following simulation studies to reveal the efficiency of our proposed algorithm in terms of localization accuracy. So, we aim to compare our proposed scheme with some other works from the literature. We cite the DV-hop [20], and some of its improvement algorithms, which are: enhanced Weighted Centroid DV-Hop (EWCL) algorithm [14], Improved Recursive (IR-DV-hop) DV-Hop algorithm [18], the localization algorithm based on the improved DV-Hop and differential evolution (DE) algorithms (DEIDV-HOP) [10] and a multi-objective DV-Hop localization algorithm based on NSGA-II (NSGA-II-DV-Hop) [28]. In order to get a comparison of the positioning performance of different algorithms more fairly, we use the average localization error formulated as follows. We adopt an isotropic network with the random deployment of nodes, and we set up the parameter α at 0.5, and the parameter C at 2 when performing all the simulations.

$$AVLE = \sum_{i=1}^{u} \frac{\sqrt{(\hat{x_i} - x_i)^2 + (\hat{y_i} - y_i)^2}}{n \times R} \times 100\% \qquad (18)$$

where $(\hat{x_i}, \hat{y_i})$ is the estimated position of the unknown node i and (x_i, y_i) is its real position. The communication range of all nodes in the network is designed by R and n presents the total number of unknown nodes that needs to be localized. We can conclude from (18) that the error of localization relies on different parameters that we will take into account for our simulations: the number of anchors, the number of unknown nodes, and the communication range of nodes.

5.2.1 Number of anchor nodes

In this experimental phase, we aim to demonstrate the impact of the variation of anchor ratio's on the local-

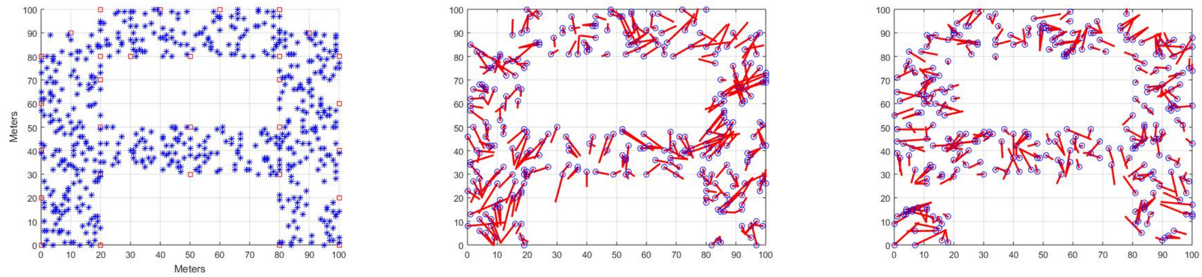


(a) Isotropic network topology with random deployment. NodeAmount: 200, AnchorAmount: 30, R=20 m

(b) Localization result of the DV-Hop algorithm. Average Localization error: 0.70

(c) Localization result of the proposed algorithm. Average Localization error: 0.27

Fig. 4 Comparison of DV-Hop and proposed algorithm on a isotropic network with random deployment of nodes

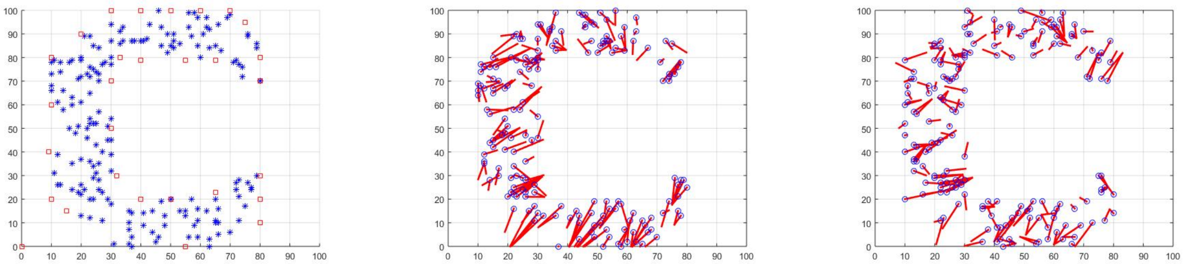


(a) A-shaped topology. NodeAmount: 350, AnchorAmount: 30, R=20 m..

(b) Localization result of the DV-Hop algorithm. Average Localization error: 0.85

(c) Localization result of the proposed algorithm. Average Localization error: 0.41

Fig. 5 Comparison of DV-Hop and proposed algorithm on a A-shaped anisotropic network



(a) C-shaped topology. NodeAmount: 200, AnchorAmount: 30, R=20 m

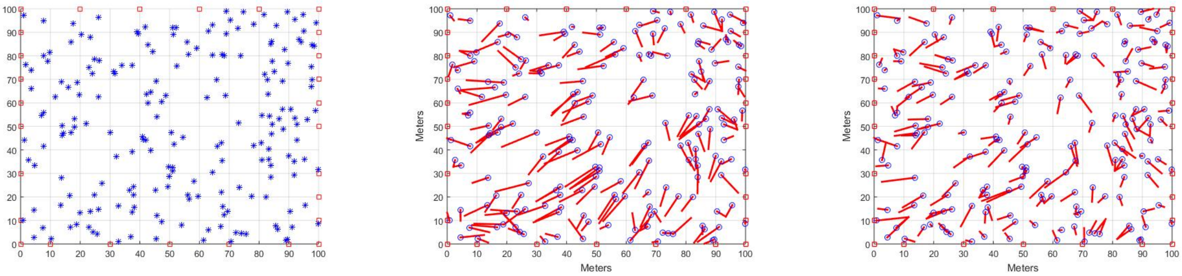
(b) Localization result of the DV-Hop algorithm. Average Localization error: 0.89

(c) Localization result of the proposed algorithm. Average Localization error: 0.45

Fig. 6 Comparison of DV-Hop and proposed algorithm on a C-shaped anisotropic network

ization performance. Then, we aim to compare our proposed algorithm in terms of localization accuracy with DV-Hop, EWCL, DEIDV-HOP, and NSGAIIDV-Hop localization algorithms. The considered network in this simulation consists of 100 sensor nodes with a communication radius of 20 meters. The number of anchors deployed varies from 10 to 35 in the sensing network area.

Fig. 10 presents the AVLE obtained by cited above localization algorithms against the number of anchor nodes. As we can see from this figure, the value of AVLE decreases as the count of anchor nodes is increased. This statement may be explained by the fact that the increase of anchor amount in the network with a static number of nodes aims to decrease the hop-count between anchors and other unknown nodes. Consequently, the estimated distance between the anchor

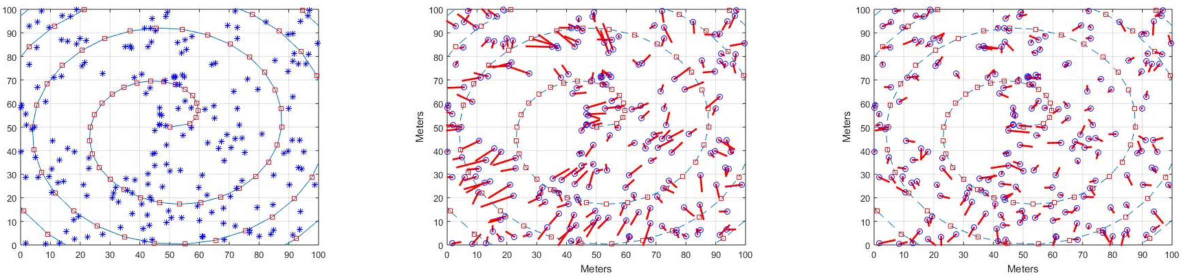


(a) Network topology with boundary anchor deployment. NodeAmount: 100, AnchorAmount: 30, R=20 m

(b) Localization result of the DV-Hop algorithm. Average Localization error: 0.70

(c) Localization result of the proposed algorithm. Average Localization error: 0.25

Fig. 7 Comparison of DV-Hop and proposed algorithm on a random deployment of nodes with boundary anchor deployment

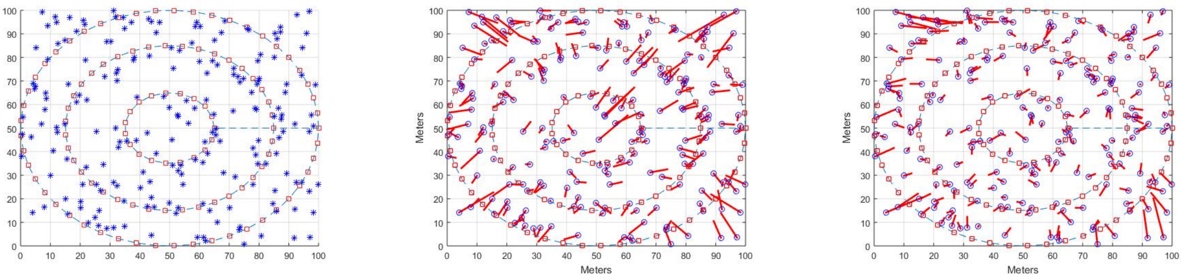


(a) Network topology with Spiral anchor deployment. NodeAmount: 200, AnchorAmount: 50, R=20 m

(b) Localization result of the DV-Hop algorithm. Average Localization error: 0.25

(c) Localization result of the proposed algorithm. Average Localization error: 0.10

Fig. 8 Comparison of DV-Hop and proposed algorithm on a random deployment of nodes with Spiral anchor deployment



(a) Network topology with circular anchor deployment. NodeAmount: 200, AnchorAmount: 60, R=20 m

(b) Localization result of the DV-Hop algorithm. Average Localization error: 0.40

(c) Localization result of the proposed algorithm. Average Localization error: 0.12

Fig. 9 Comparison of DV-Hop and proposed algorithm on a random deployment of nodes with circular anchor deployment

and the unknown node corresponds more to the real distance. Hence, the average positioning error will decrease. Also, it can be seen from this figure that the resulted localization error in the proposed algorithm is lower than that in all other compared algorithms. Besides, the proposed algorithm positioning accuracy increased by up to 60%, 4%, 52%, 30% compared with DV-Hop, DEIDV-HOP, IRDV-Hop, and NSGAII-DV-hop respectively. Therefore, our algorithm outperforms in terms of localization accuracy in comparison with the other four algorithms.

5.2.2 Total Number of Nodes

By this second experimental phase, we aim to demonstrate the impact of the variation of the total number of nodes deployed in the sensing field on the localization performance. Also, we aim to evaluate the proposed al-

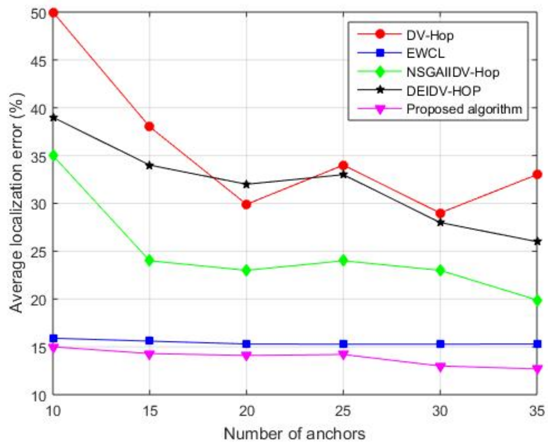


Fig. 10 Number of anchor nodes vs. localization error

gorithm in terms of localization performance versus the original DV-Hop, DEIDV-HOP, NSGAIIDV-Hop, and IRDV-Hop localization algorithms. We consider a sensing network consisting of 10% anchor nodes of the total count of nodes, which is varying from 50 to 400. The communication radio is supposed to be 20 meters.

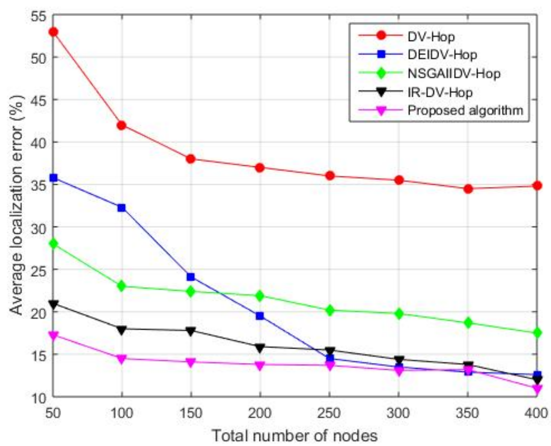


Fig. 11 Total number of nodes VS. localization error

Fig. 11 shows the AVLE obtained by the cited above localization algorithms against the total number of nodes. As we can notice from this figure, the localization error decreases with the increase in the total number of nodes. This result is expected because the increase of the number of nodes leads to an increase in the count of neighbors of every sensor in the sensing field. Thus, the high density of the network leads to improve connectivity, so the estimation of the average distance of hops becomes more precise. Then, the estimated distance between the anchor and the unknown node will be more reliable. As a conclusion, the localization accuracy is improved. As it can be observed from Fig. 11, our proposed algorithm leads to obtain the least localization error than that of its counterparts. Besides, using the proposed algorithm, each node can estimate its position with a little value of localization error which is less than 54% in comparison with the DV-Hop algorithm. From these results, we can prove the high performance of the proposed localization algorithm in comparison with its counterparts.

5.2.3 Communication radius of nodes

In this third experimental phase, we aim to examine the effect of communication radius variation on the localization accuracy. So, as the communication range is varied, we perform an evaluation of our proposed algorithm in terms of localization accuracy versus DV-Hop, DEIDV-HOP, NSGAIIDV-Hop, and IRDV-Hop localization algorithms. The simulation parameters are 100 nodes deployed in $100 \times 100m^2$ sensing field, the total number of anchor nodes is 20%, and the communication range R of each node varies from 20 to 40 meters. We note that all nodes have the same communication range in the network. Fig. 12 illustrates the AVLE of the proposed localization algorithm and that of the other cited algorithms against the changing of R of nodes.

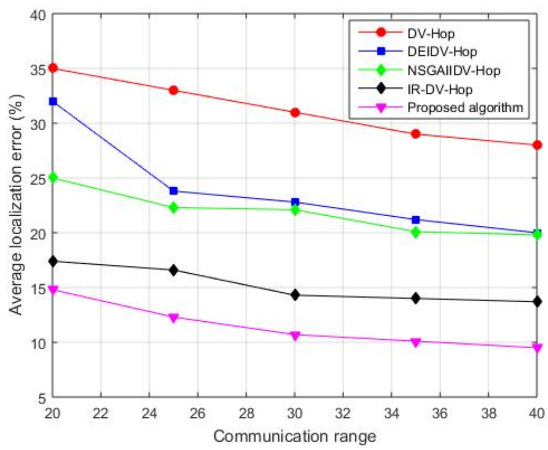


Fig. 12 Communication range VS. localization error

From Fig. 12, we perceive that the AVLE of DV-Hop, DEIDV-HOP, NSGAIIDV-Hop, and IRDV-Hop as well as the proposed localization algorithm decreases while the radio range R is increasing. This result can be explicated as follows: when the communication radius increase, the communication range of each node becomes major, thus every adjacent node will establish a single-hop communication with the node, and the network connectivity is then improved. Moreover, the hop-

count value between the unknown node and the anchor node is reduced. So, the estimation of the average distance of hops by the algorithm and the number of hops between nodes becomes more precise. Therefore, the estimation of the distance between the unknown node and anchor is also more accurate, which leads to obtaining an accurate coordinates of the unknown node.
As in Fig. 12, compared with DV-Hop, DEIDV-HOP, NSGAIIDV-Hop, and IRDV-Hop, the positioning accuracy of the proposed algorithm is improved by 25%, 15%, 12%, and 8% respectively. Then, the proposed localization technique yields better positioning precision when compared with the rest of cited algorithms.

5.3 Effect of Irregular communication patterns on localization accuracy

In the case of real sensor network deployment applications, many environmental influences, such as noise, can affect radio signals, thus the communication radius of sensor nodes will be in the form of an anomalous polygon instead of a standard circle. In order to characterize the radio signal transmission irregularity, Tian He et al. [13] defined The degree of irregularity (DOI) model. This model exhibits the maximal fluctuation of radio per unit degree change within various directions of radio propagation [17].

The probability of communication, as in [22], between two distant nodes within a corresponding distance d is as follows:

$$P(d) = \begin{cases} 1, & \frac{d}{R} < 1 - DOI, \\ \frac{1}{2DOI}(\frac{d}{R} - 1) + \frac{1}{2}, & 1 - DOI \leq \frac{d}{R} \leq 1 + DOI, \\ 0, & \frac{d}{R} > 1 + DOI. \end{cases}$$

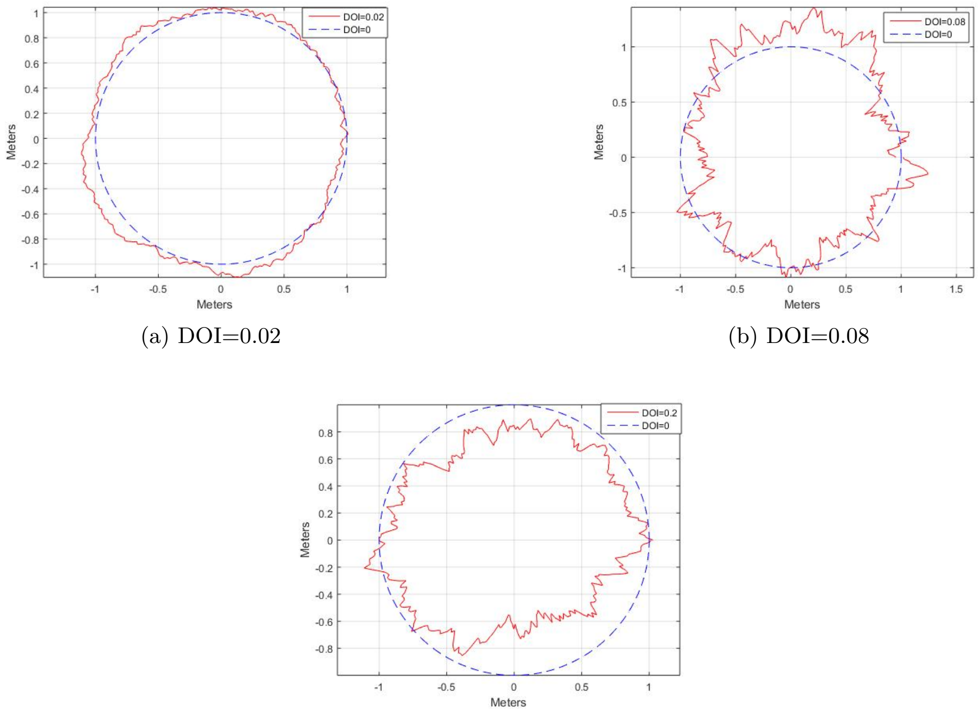
Fig. 13 shows the variation of the transmission range with different values of DOI. In the case of DOI=0, the transmission range takes the form of an ideal circle. Otherwise, if DOI increases, we can see from Fig. 13 that the irregularity of the transmission range increases.

To show the effect of the irregularity of radio range on the proposed DV-hop based localization algorithm, and come up with the relation between localization accuracy and DOI, we execute our algorithm with a radio range irregular model. The proposed network is consisting of 200 sensors randomly deployed in a sensing area of 100×100 meters, where number of anchors varies from 10 to 35. We suppose that all nodes communicate within the same transmission range of radius R. The DOI is varied from 0 to 0.08.

Fig. 14 shows the variation of Average Localization Error (AVLE) resulted from the proposed algorithm for a different number of anchors and different values of DOI. One can see from this figure that when the DOI increases, the localization error also increases. This result is expected because the increase of DOI aims to minimize the connectivity of the network, then the localization accuracy will be also minimized.

6 Conclusion

To improve localization accuracy in both isotropic and anisotropic WSNs, an improved Regularized Least Square DV-Hop localization algorithm (RLS-DV-Hop) is proposed in this research paper. The proposed technique combines the double Least Square localization method with the statistical filtering optimization strategy, which is the Regularized Least Square method. The main concept of our proposed technique is to reduce the quadratic localization errors. Simulations are performed in order to compare the proposed scheme in terms of localization accuracy with the original DV-Hop and other recent algorithms from the literature, using MATLAB 2015a. Simulation results proved that RLS-DV-Hop can effectively reduce localization error with up to 60% when compared with the original DV-Hop. Also, our method outperforms in terms of localization accuracy in comparison with the other cited localization algorithms.



(a) DOI=0.02

(b) DOI=0.08

(c) DOI=0.2

Fig. 13 Irregular radio patterns for different values of DOI

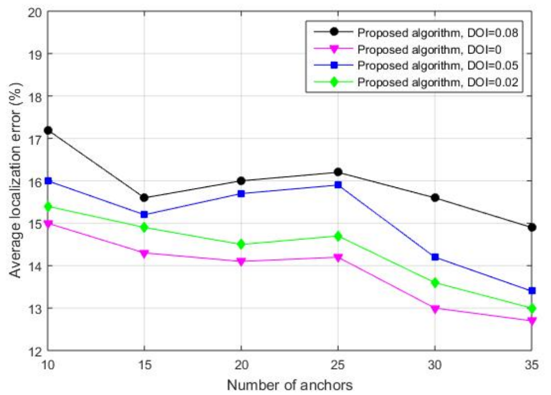


Fig. 14 Comparison of localization errors with different radio range of nodes and different degrees of radio propagation irregularity DOI

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Conflict of interest

The authors declare that they have no conflict of interest.

Availability of data and material

Not applicable.

Code availability

Not applicable.

Authors' contributions

Not applicable.

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