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Regularized Least Square Multi-Hops Localization Algorithm for Wireless Sensor Networks

HEND LIOUANE¹, SANA MESSOUS¹, OMAR CHEIKHROUHOU^{2,3}, MOHAMMED BAZ⁴, AND HABIB HAMAM^{5,6}, (Senior Member, IEEE)

¹Research Laboratory of Automatic Signal and Image Processing (LARATSI), National Engineering School of Monastir, University of Monastir, Monastir 5000, Tunisia

²CES Laboratory, National School of Engineers of Sfax, University of Sfax, Sfax 3038, Tunisia

³Higher Institute of Computer Science of Mahdia, University of Monastir, Monastir 5000, Tunisia
⁴Department of Computer Engineering, College of Computer and Information Technology, Taif University, Taif 21994, Saudi Arabia

⁵Faculty of Engineering, Université de Moncton, Moncton, NB E1A3E9, Canada

⁶Department of Electrical and Electronic Engineering Science, University of Johannesburg, Johannesburg 2006, South Africa

Corresponding author: Hend Liouane (hend.louane@issatkr.rnu.tn)

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ABSTRACT Position awareness is very important for many sensor network applications. However, the use of Global Positioning System receivers to every sensor node is very costly. Therefore, anchor based localization techniques are proposed. The lack of anchors in some Wireless Sensor Networks lead to the appearance of multi-hop localization, which permits to localize nodes even if they are far from anchors. One of the well-known multi-hop localization algorithms is the Distance Vector-Hop algorithm (DV-Hop). Although its simplicity, DV-Hop presents some deficiencies in terms of localization accuracy. Therefore, to deal with this issue, 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. We used the double Least Square method. 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.

INDEX TERMS Distance vector-hop algorithm, localization, localization accuracy, regularized least square, multi-hop wireless sensor networks.

I. INTRODUCTION

Nowadays, the Internet of Things (IoT) is a promising technology which aims at a revolutionary development and connects the global world via smart connected physical devices. The Fifth generation (5G) mobile network is an emerging IoT standard which is a potential key enabler for future IoT by solving the drawbacks of previous standards. The Wireless Sensor Network (WSN) is one of the basic supporting technologies of 5G system [1], [2]. Besides, WSN is considered as one of the hottest research topics under the spotlight worldwide [3]. Moreover, WSN technology is applied in many fields including military, industry [4], medicine, environmental monitoring [5], and so on. Regarding wireless sensor nodes, they can be deployed in an isotropic and anisotropic

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way, as seen in Fig. 1. In the case of isotropic deployment (Fig. 1a), sensor devices are deployed in an uniform distribution. However, in the case of anisotropic deployment, as shown in Fig. 1b, sensors are deployed in sparse distribution due to the existence of holes or obstacles. In Fig. 1, a dashed line represents the physical distance between two nodes in the network, and straight line with arrows indicates the real path between each two nodes. One can see that the proportionality of the physical distance and the real path between each node depends on the type of node deployment. Besides, a better proportionality is observed in the case of isotropic deployment of nodes. So, in the case of anisotropic network, the use of the hopCount between two unknown nodes is not a precise method for distance estimation.

Sensor nodes collect data from their sensing field. The collected information depends on the locations of sensor nodes. Thus, without accurate positions of sensor nodes,



(a) Isotropic deployment nodes

FIGURE 1. Deployment nodes classification.

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 fundamental key in many wireless applications. The Global Positioning System is an accurate method for localization, but it is an energy consuming technique. Once sensor nodes have several resource constraints such as limited battery power [6], [7], the Global Positioning System (GPS) is not an effective solution for localization problem in WSN. Therefore, many localization techniques have been proposed by researchers regarding this issue.

The most commonly used localization methods in the literature are summarized in [8]-[10]. These localization techniques are mainly classified as range-based and rangefree [9]. Range-based methods are based on the distance or angle metric between sensor nodes. The most used techniques are the Received Signal Strength Indicator (RSSI) [11], Angle of Arrival (AOA) [12], Time of Arrival (TOA) [13], and Time Difference of Arrival (TDOA) [14]. Also, several localization techniques based on artificial intelligence and meta-heuristic algorithms such as fuzzy logic and neural network, PSO and GA have been used for WSN routing and localization optimization [15], [16]. 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 range-based methods, range-free methods, reduce their requirements over sensor node hardware, and have wide advantages in costs and energy 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 [17], APIT [18], DV-Hop [19], Bounding Box algorithm [20], and Sequence-Based algorithm [21]. These methods are known as connectivity-based algorithms. Traditionally, the popular DV-Hop algorithm, as a range-free



(b) Anisotropic deployment nodes in A-shaped topology

technique, uses the Global Positioning System (GPS) [22] 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 [23]. 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.

Our work in this manuscript consists on an improvement of DV-Hop localization algorithm. Besides, our proposed technique is based on an improved Regularized Least Square DV-Hop localization algorithm (RLS-DV-Hop). This method is a statistical filtering optimization strategy combined with the double Least Square localization method. The main concept of our proposed technique is to reduce the localization error.

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.

II. 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. Therefore, 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 computational complexity [24].

Indeed, in [25], 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 [26], the authors proposed a multi-hop range-free localization algorithm based on Least Square Regularized Regression for WSNs. Simulation results proved that the proposed algorithm minimizes the localization error. Following the machine learning process, this paper presents an interesting model for localization in WSN for isotropic and anisotropic cases. In fact, considered as the learning phase, the authors estimated the distance between anchors and unknown nodes via the Least Square Regularized Regression (LSRR) model. Moreover, the maximum likelihood method is also used to estimate the coordinates of unknown nodes. Unlike LSSRR-LA, our proposed method uses the cascade LSSR for hop-size estimation and the localization process and can be considered as an improved version of the LSRR-LA proposed in this paper.

Paper [24] deals with the problem of localization optimization using the Locally Weighted Linear Regression (LWLR) technique. Indeed, each anchor is associated with a weight according to the number of hops. If the number of hops is higher than three, the anchor will be penalized when applying the localization process via the weighted multilateration. Moreover, the kernel method is used to increase the weight of the nearest anchor nodes. The LWLR regression process automatically selects the best subsets of anchor nodes candidates for the localization process via the weighted DV-Hop algorithm. Indeed, this method gives weak results if the number of anchors is not enough or if there are not efficient anchors positions.

In [27], 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 leads to large errors and low localization accuracy.

Authors in [28] 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) [29], and the Weighted DV-Hop (WDV-Hop) [30]. 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 called Reliable Anchor-based Localization algorithm (RAL) for WSN localization problem was presented. The main idea 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 of sensor in the WSN, hop-count, and Degree of Radio Irregularity (DOI) [23] which minimizes radio signal propagation irregularities. Additionally, the algorithm requires more 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 intersensor 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 [32] 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 distance estimation accuracy.

In [33] 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.

In this paper, we propose a multi-hop range-free localization algorithm based on Least Square Regularized Regression for distances estimation in WSNs. The aim of our work is minimizing the localization error.

III. REVIEW OF THE DV-HOP ALGORITHM

Assisted by the anchor position, the fundamental concept of DV-Hop algorithm [19] 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 forward 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).

$$HopSize_{i} = \frac{\sum_{i \neq j}^{n} \sqrt{(x_{i} - x_{j})^{2} + (y_{i} - y_{j})^{2}}}{\sum_{i \neq j}^{n} h_{ij}}$$
(1)

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

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

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

where $h_{i,j}$ is the minimum hop-count between anchor a_i and unknown node u. and HopSize_i is the average distance of hop of anchor *i*.

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:

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

$$AX = B \tag{4}$$

where

$$X = \begin{pmatrix} x_{u} \\ y_{u} \end{pmatrix}$$

$$A = -2 \times \begin{pmatrix} x_{1} - x_{n} & y_{1} - y_{n} \\ x_{2} - x_{n} & y_{2} - y_{n} \\ \vdots \\ x_{n-1} - x_{n} & y_{n-1} - y_{n} \end{pmatrix}$$

$$B = \begin{pmatrix} d_{1,u}^{2} - d_{n,u}^{2} - x_{1}^{2} + x_{n}^{2} - y_{1}^{2} + y_{n}^{2} \\ d_{2,u}^{2} - d_{n,u}^{2} - x_{2}^{2} + x_{n}^{2} - y_{2}^{2} + y_{n}^{2} \\ \vdots \\ d_{n-1,u}^{2} - d_{n,u}^{2} - x_{n-1}^{2} + x_{n}^{2} - y_{n-1}^{2} + y_{n}^{2} \end{pmatrix}$$

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.

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

Then, we get:

$$\begin{aligned} x &= X(1) \\ y &= X(2) \end{aligned}$$

IV. 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:

A. STEP 1: WSN DISCOVERY

The first step of our proposed algorithm works like the first step of the original DV-Hop algorithm, where the minimum hop-count between all nodes is determined. Firstly, the number of hops between the available anchor nodes are computed 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 nn presented the number of unknown nodes.

B. 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 as follows:

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

$$Hca \cdot \Omega = Da \tag{7}$$

The solution of equation 5 can be given using the least square solution [34]. Then, the obtained solution and the objective function are expressed as follows:

$$\Omega = arg_{\Omega} \ min||Hca \times \Omega - Da||^2 \tag{8}$$

where $||.||^2$ is the L_2 -norm. *Hca* is the hop-count matrix between anchor nodes, and *Da* is the correspondent distance matrix.

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:

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

$$\Omega = Hca^+ \cdot Da \tag{10}$$

where

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

The Hca^+ represents the Moore-Penrose generalized inverse matrix [35] of *Hca*. Therefore, Ω can be expressed as follows:

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

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

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

I is the Identity matrix, and *C* is a constant to be adjusted during the simulation process. The matrix $\frac{1}{C} * I$ is presented as follows.

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

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:

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

C. 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 the network Da and the geographical position matrix Xa is given by the next linear equation:

$$Da \cdot \Psi = Xa \tag{15}$$

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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

The least square solution is given by the following formula:

$$\Psi = Da^+ \cdot Xa \tag{16}$$

where $Da^+ = (Da^T Da)^{-1} Da$.

The expected geographical position of the unknown sensor node can be given as follows:

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

Fig. 2 and Fig. 3 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 $20 \ m \times 20 \ m$ as shown in Fig. 4. 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.

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.

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:

As seen in Table 5, the resulted estimated position of UN using the proposed approach 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.



(a) Identification of the Hop-size



(b) Identification of the localization parameters



(c) Localization of unknown nodes





FIGURE 3. Localization model based RLS Algorithm.

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

V. 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.* [18] 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 [3].

The probability of communication, as in [23], between two distant nodes within a corresponding distance d is as follows:

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

Fig. 5 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. 5 that the irregularity of the transmission range increases.



FIGURE 4. Localization example.

TABLE 3. Estimated HopSize matrix 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{Dn}	A1	A2	A3	A4	
UN	15.69	20.04	5.81	15.69	

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

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 the number of anchors varies from 10 to 35. We suppose that all



FIGURE 5. Irregular radio patterns for different values of DOI.

TABLE 6. Comparison of the estimation error in the proposed example.

	Accuracy	
DV-Hop algorithm	0.59	
Proposed algorithm	0.13	

nodes communicate within the same transmission range of radius R, and the DOI is varied from 0 to 0.08, because as seen in Fig. 5b the variation of radio range at DOI = 0.08 is very similar to the real variation in real conditions.

Fig. 6 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.

VI. 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 [19], enhanced Weighted Centroid DV-Hop (EWCL) algorithm [36], Improved Recursive (IR-DV-hop) DV-Hop algorithm [37], the localization algorithm based on the improved DV-Hop and differential evolution (DE) algorithms



FIGURE 6. Comparison of localization errors with different radio range of nodes and different degrees of radio propagation irregularity DOI.

(DEIDV-HOP) [38], a multi-objective DV-Hop localization algorithm based on NSGA-II (NSGA-II-DV-Hop) [39] and multi-hop range-free localization algorithm based on Least Square Regularized Regression (LSRR) [26]. 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. In order to get a comparison of the positioning performance of different algorithms more fairly, we use the average localization error formulated as follows.

$$AVLE = \sum_{i=1}^{u} \frac{\sqrt{(\hat{x}_i - x_i)^2 + (\hat{y}_i - y_i)^2}}{n}$$
(18)



(a) Isotropic network topology with random deployment. * Unknown node, \Box Anchor. NodeAmount: 200, AnchorAmount: 30, R=20 m





(c) Localization result of the proposed algorithm. AVLE: $3.85~\mathrm{m}$



TABLE 7. Comparison of AVLE under different anchor distributions in isotropic random deployment network.

Anchor distribution AVLE (m)	Boundary	Spiral	Circular
DV-Hop algorithm	50.3	31.2	40.6
IR-DV-Hop	39.2	25.4	30.6
Proposed algorithm	28.3	20.5	17.9

TABLE 8. Impact of the variation of parameter C on AVLE of the proposed algorithm in the case of isotropic network.

Parameter C	1	0.1	0.01	0.001	0.0001	0.00001	0.000001
AVLE	$1.25^{*}R$	$0.78^{*}\mathrm{R}$	$0.45^{*}\mathrm{R}$	$0.25^{*}\mathrm{R}$	$0.21^{*}\mathrm{R}$	$0.18^{*}\mathrm{R}$	$0.17^{*}\mathrm{R}$

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 total number of unknown nodes that needs to be localized is presented by *n*. The reported results of all comparisons are the average over 100 trials for better simulation results.

A. SIMULATION RESULTS UNDER AN ISOTROPIC NETWORK

1) DIFFERENT TOPOLOGIES OF NETWORK

In a first experiment, we aim to show the localization results and highlight the localization error of sensor nodes of both the proposed algorithm and the DV-Hop algorithm, in an isotropic network. Sensor nodes are deployed in the sensing field in a random way. The network size is set to $100 \times 100 m^2$. Network topology as well as localization results are shown in Fig. 7. We denote the anchor node by a red square symbol 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.

As seen in Fig. 7, the average localization error obtained in the proposed algorithm is much lower than that obtained in the DV-Hop algorithm under both the two different topologies. Besides, the accuracy of localization is well improved by our proposed algorithm.

In a second experiment, 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 and Improved Recursive DV-Hop algorithms (IR-DV-hop) [37] has been proceeded under different anchor deployment schemes: boundary, spiral, and circular distributions.

Table 7 summarizes the obtained localization error with different anchor placement types. One can see from these 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 and the IR-DV-Hop algorithms 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.

Then, in a third experiment, we aim to compare our proposed scheme in a random isotropic sensor network with some other works from the literature: DV-hop [19], and some of its improvement algorithms, which are: enhanced Weighted Centroid DV-Hop (EWCL) algorithm [36], Improved Recursive (IR-DV-hop) DV-Hop algorithm [37], the localization algorithm based on the improved DV-Hop and differential evolution (DE) algorithms (DEIDV-HOP) [38], multi-objective DV-Hop localization algorithm based on NSGA-II (NSGA-II-DV-Hop) [39] and multi-hop range-free localization algorithm based on Least Square Regularized Regression (LSRR) [26]. We conduct the simulations experiments according to the following parameters: the number of anchors, the number of unknown nodes and



FIGURE 8. Number of anchor nodes vs. localization error.



FIGURE 9. Total number of nodes VS. localization error.

the communication range of nodes. We adopt an isotropic network with the random deployment of nodes, and we set up the parameter $C = 1/\alpha$ at 10^{-5} when performing all the simulations. The impact of the parameter *C* on the AVLE of the proposed algorithm is shown in Table 8, in a network composed of 200 unknown nodes and 30 anchors. As seen from this table, when the value of *C* tends to zero, the AVLE decreases. Therefore, the value of the parameter *C* must be very small in order to get a small value of AVLE.

2) NUMBER OF ANCHOR NODES

In this experimental phase, we aim to demonstrate the impact of the variation of anchor ratio's on the localization performance.

Then, we aim to compare our proposed algorithm in terms of localization accuracy with DV-Hop, EWCL, DEIDV-HOP, NSGAIIDV-Hop localization algorithms. We conduct simulations with a network composed 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. 8 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 and



FIGURE 10. Communication range VS. localization error.

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, IR-DV-Hop, and NSGAII-DV-hop respectively. Therefore, our algorithm outperforms in terms of localization accuracy in comparison with the other four algorithms.

3) 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 algorithm in terms of localization performance versus the original DV-Hop, DEIDV-HOP, NSGAIIDV-Hop, and IR-DV-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. 9 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. 9, 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.

TABLE 9. Impact of the variation of parameter C on AVLE of the proposed algorithm in the case of anisotropic network.

Parameter C	1	0.1	0.01	0.001	0.0001
AVLE	$0.25^{*}\mathrm{R}$	$0.39^{*}\mathrm{R}$	$0.55^{*}\mathrm{R}$	$0.83^{*}\mathrm{R}$	$1.21^{*}R$



(a) Localization result of the DV-Hop algorithm. \circ : Real location of the unknown node, Red straight line: localization error. Average Localization error: 85 m



(b) Localization result of the proposed algorithm. o: Real location of the unknown node, Red straight line: localization error: 34 m

FIGURE 11. Comparison of DV-Hop and proposed algorithm on a A-shaped anisotropic network.

Number of anchors	N-65	N_{-75}	N_95	N-05	N.

TABLE 10. Comparison of AVLE under different number of anchors in anisotropic random deployment network.

Number of anchors Algorithm	N=65	N = 75	N = 85	N = 95	N=105
DV-Hop algorithm	192.2	190.6	186.4	186.9	188.2
LSRR-LA	38.9	39.4	38.3	35.7	34.8
Proposed algorithm	37.8	38.7	34.8	30.9	29.9

4) COMMUNICATION RADIUS OF NODES

In this third experiment, we aim to examine the effect of communication radius value on the localization accuracy. Moreover, 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 100×100 meters 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. 10 illustrates the AVLE of the proposed localization algorithm and that of the other cited algorithms against the changing of *R* of nodes.

From Fig. 10, we perceive that the AVLE of DV-Hop, DEIDV-HOP, NSGAIIDV-Hop, and IR-DV-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. 10, compared with DV-Hop, DEIDV-HOP, NSGAIIDV-Hop, and IR-DV-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.

B. SIMULATION RESULTS UNDER AN ANISOTROPIC NETWORK

In the case of anisotropic deployment, which reflects realistic deployment conditions, sensor nodes are deployed in a sensing field that holds obstacles, such as buildings, pieces of equipment, etc. In fact, these conditions cause 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. Network topology as well as localization results are shown in Fig. 11 and Fig. 12. The communication range is 100 meters. The real location of the unknown node is presented by the blue circle and the red straight line marks the error of localization. The parameter C affects the AVLE of the proposed algorithm as shown in Table 9. One can see form this table that the decreasement of parameter C aims to increase the value of



(a) Localization result of the DV-Hop algorithm. o: Real location of the unknown node, Red straight line: localization error: 89 m



(b) Localization result of the proposed algorithm. ◦: Real location of the unknown node, Red straight line: localization error. Average Localization error: 22 m

FIGURE 12. Comparison of DV-Hop and proposed algorithm on a C-shaped anisotropic network.

TABLE 11. Comparison of AVLE under different communication range in anisotropic random deployment network.

Communication range Algorithm	R=100	R=150	R=200	R=250	R=300
DV-Hop algorithm	266.4	156.3	112.6	87.4	71.5
LSRR-LA	53.5	44.4	38.9	33.8	32.3
Proposed algorithm	26.8	34.6	37.6	47.7	47.3

AVLE. Therefore, the value of the parameter C must be approximate to 1 in order to get a small value of AVLE.

One can see from Fig. 11 and Fig. 12 that the position 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 anisotropic wireless sensor networks.

1) COMPARISON OF AVLE UNDER ANCHOR AMOUNT VARIATION

350 nodes are randomly deployed in $1000 \times 1000 m$. Table 10 presents the AVLE results of the original DV-Hop algorithm, LSRR-LA algorithm and the proposed algorithm when the communication range *R* is 150 m and the number of anchors N varies from 65 to 105.

As shown in table 10, the proposed algorithm presents the lower AVLE compared with the two other algorithms.

2) COMPARISON OF AVLE UNDER RADIO COMMUNICATION VARIATION

350 nodes are randomly deployed in $1000 \times 1000 m$. The comparison of the AVLE results of the original DV-Hop algorithm, LSRR algorithm and the proposed algorithm is presented in table 11 where the total amount of anchors is 70 and the communication range *R* varies from 100 to 300 meters.

Results shown in table 11 prove that the AVLE of the proposed algorithm is lower when compared with that of the DV-Hop and the LSRR-LA algorithms.

VII. 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 is an improvement of the original DV-Hop algorithm. It aims to minimize the localization error caused when estimating the distance between anchors and unknown nodes by combining the double Least Square localization method with the statistical filtering optimization strategy, which is the Regularized Least Square method. 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.

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DECLARATION

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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HEND LIOUANE received the Ph.D. degree in automatic from the National School of Engineers of Monastir Tunisia (ENIM), in 2010. Her research interests include WSN control, evolutionary optimization, multi-agent optimization systems, and smart computing.



SANA MESSOUS received the Diploma degree in electronical engineering from the National School of Electronics and Telecommunication (ENET'Com) of Sfax, Tunisia, in 2016, and the Ph.D. degree in electrical engineering from the National School of Engineers of Monastir Tunisia (ENIM), in 2021. Her research interest includes localization algorithms and optimization in wireless sensor networks.



OMAR CHEIKHROUHOU received the B.S., M.S., and Ph.D. degrees in computer science from the National School of Engineers of Sfax, in March 2012. He is currently an Assistant Professor with the College of Computer and Information Technology, Taif, Saudi Arabia. He is also a member of the Computer and Embedded System (CES) Laboratory, University of Sfax, and National School of Engineers. His Ph.D. deals with security in wireless sensor networks and more

precisely in secure group communication in wireless sensor networks. He has several publications in several high-quality international journals and conferences. His research interests include wireless sensor networks, cybersecurity, and multi-robot system coordination. He has received some awards, including the "Governor Prize" from the Governor of Sfax in 2005.



MOHAMMED BAZ received the Ph.D. degree in applications of statistical inference on designing communication protocols for low-power wireless networks from the University of York, in 2015. He currently works with the Computer Engineering Department, College of Computers and Information Technology, Taif University. He is the author of a number of published papers in recognized conferences and has acted as a reviewer for a number of IEEE journals, including

IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, IEEE ACCESS journal, and IEEE WIRELESS COMMUNICATIONS LETTERS. He has been a member of multiple

committees related to academic fields as well as participant in research projects. Moreover, he has taught several courses and supervised several capstone projects.



HABIB HAMAM (Senior Member, IEEE) received the B.Eng. and M.Sc. degrees in information processing from the Technical University of Munich, Germany, in 1988 and 1992, respectively, the Ph.D. degree in physics and applications in telecommunications from the University of Rennes I conjointly with France Telecom Graduate School, France, in 1995, and the Postdoctoral Diploma degree "Accreditation to Supervise Research in Signal Processing and Telecommu-

nications" from the University of Rennes I, in 2004. From 2006 to 2016, he was a Canada Research Chair holder in "Optics in Information and Communication Technologies," for a period of ten years. He is currently a Full Professor with the Department of Electrical Engineering, University of Moncton. His research interests include optical telecommunications, wireless communications, diffraction, fiber components, RFID, information processing, data protection, COVID-19, and deep learning. He is a Senior Member of OSA, and a Registered Professional Engineer in New-Brunswick. He is among others Editor-in-Chief of *CIT-Review* and an Associate Editor of the *IEEE Canadian Review*.

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