Improved Least-Square DV-Hop Algorithm for Localization in large scale wireless sensor network

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***Abstract*—Certain applications of wireless sensor networks require that the sensor nodes should be aware of their position relative to the sensor environment. Generally in the applications of positioning in the internet of things (IoT), there is a deficiency of localization precision and concrete results. It is really important to maintain high-efficient localization schemes for the Internet of things, especially for wireless sensor networks. For that, an improved DV-hop algorithm is proposed in this paper to move for more accurate results based on the least square method. Therefore, the weight coefficient is calculated between an anchor node and the other anchor nodes using the mean square method. Then, this weighting coefficient, the hop size, will be applied between the unknown nodes and the anchor nodes in order to determine the distances. The computed hop-size average significantly enhances the positioning accuracy which is approved by the experiments that explain how suitable this improved Last-Square DV-hop Algorithm is for localization in WSN.**

***Index Terms*—WSN, DV-Hop, Localization, Least-square**

I. Introduction

The wireless sensor network known as “WSN” is a trend of network structure that has been raised by the advances in MEMS technology thanks to its wireless communication support and its low cost to revolutionize the behavior and operation of several current embedded systems applications. A large-scale wireless sensor network holds a big number of tiny sensor nodes that are densely deployed either inside the occurrence to be sensed or very close to it. In recent years, wireless sensor networks have attracted global research interest in the scientific community and industrial applications, due to their broad applications such as healthcare, smart homes, and environmental monitoring. For these applications, the location of communicating equipment is an important issue because it often conditions their proper functioning. For all applications of wireless sensor networks, the geolocation of accurately communicating sensor nodes remains an important issue for researchers and manufacturers. Conventionally, the existing localization algorithms can be classified into two categories known as “range-based” and “range-free”. The drawbacks related to “Range-based” are considered major where the location systems are expensive considering the additional equipment needed to measure distances between nodes. Moreover, several parameters related to the nature of the network and the environment like the humidity level and the electromagnetic noise affect the precision of the measurements. On the other hand, the ”range-free” surpasses these two disadvantages by exploiting the notions of connectivity and hops [1]. Indeed, to estimate the target nodes’ position request to collect network connectivity information as well as the position of the anchors and evaluate the distance which is adapted to any type of wireless transmission and then calculate their positions without additional hardware for measuring. The alternative range-free localization techniques are represented by Amorphous [2],Centroid [3], Approximate Point in Triangle Test (APIT) [4] and Distance Vector-Hop (DV-Hop) [5], etc. The Distance Vector-Hop (DV-Hop) algorithm attracts more attention thanks to its low hardware requirement and feasibility. The traditional DV-Hop performs well in the isotropic and uniform networks [6] which is rational to get an accurate position from every average hop distance. In fact, the DV-Hop process consists of three stages, first, flooding where each anchor node transmits its location through all nodes in the network with hop count initialized to 0 incremented by one whenever the packet is forward to the neighboring nodes. Thus each unknown node knows the minimum hops for each anchor node. Second, after the flooding stage is finished, the calculation of the range distance, the average size of hops (hope size), of each anchor is calculated using the minimum number of hops and the distance between anchor nodes. Then, based on the least hops determining the distance between an unknown node and its nearest anchor. The number of these hops multiplied by the hop size determines the distance between the unknown node and that anchor. Third, this stage consists of calculating the position of the unknown node using the trilateration method. Although when the network is Non-uniform, the hop size calculated by the hop information received by the nodes has important estimation errors that affect the node location accuracy [7]. So in this paper, we have been carried out to solve the drawbacks of the traditional DV-Hop algorithm by creating an optimized algorithm. We improve the traditional DV-Hop by an intervention in the second stage where amelioration of

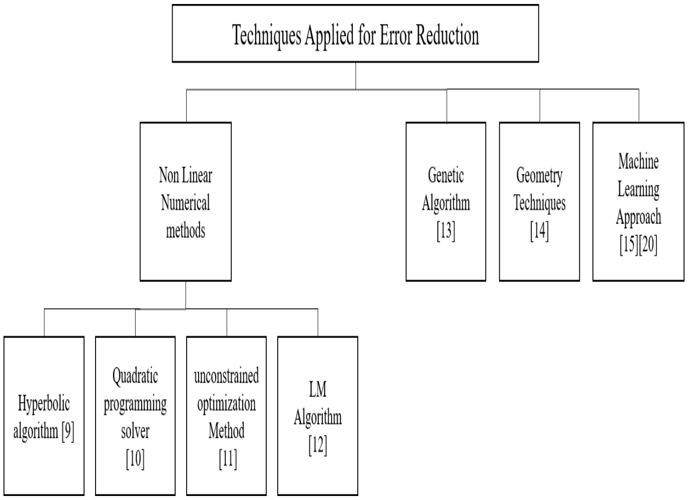

Fig. 1. Classification based on Error Detection

the hop-size takes place in order to reduce distance estimation error using regularized least square method. We conducted extensive simulation experiments to validate the efficiency of the improved algorithm. We found that our optimized localization algorithm is better than that of the original DV-Hop. The rest of this paper is structured as follows. Section 2 is about the related works, section 3 is related to the basic DV-Hop algorithm. In section 4, the improved Least-Square DV-Hop algorithm is stated. In section 5, experimental results are presented and analyzed. In section 6, we conclude this paper .

II. Related works

Among the well-known localization algorithms, the DV-Hop algorithm is advantageous due to its simplicity, feasibility and robustness unless its localization accuracy. As a result, several additional techniques were applied to reduce the error in localization due to the original DV-Hop algorithm limitation in the exploitation of the least square method. These techniques are divided into various subcategories as referenced in Fig.1 principally Nonlinear Numerical methods, Weighted approach, Geometry Techniques, Nature Inspired Algorithms, Hybrid Approach, Machine Learning Approach. Previous to 2016, the main rectifications were mainly based on phase 2 and phase 3. Posterior, the tendency to move for refinement in phase 1 [8].

III. DV-Hop Localization Algorithm

The DV-Hop algorithm is involved in this article to handle localization of nodes by a new developed method for the valuation of the average distance of hops between nodes.

A. The original DV-Hop Localization algorithm description

In the introduction, we have shortly presented the process of DV-Hop. In this subsection, A detailed overview of the original DV-Hop algorithm will be described. The unknown node localization process was developed in 3 steps, as follows. step1, known as the flooding phase, each anchor node within the sensing network spreads its position and the hop-count via a packet into the whole network. The hop-count value is initialized to 0 then each packet transitions from node to its neighbor the hop-count is incremented by 1. Every node receives these packets containing the positions and the hop-count values from the transmitter anchor. (x_i,y_i, h_i) form the information broadcasts the entire network, where (x_i,y_i) is the location of the anchor i and h_i the hops' value to reach the anchor i. Sequentially, the reception nodes made an update of their information while getting a hop-count value less than the recorded value received from the same anchor. Then this updated packet will be forwarded to its neighbor nodes to get updated packets too. By the end of this task, every node sustains an information packet containing the position of the anchor nodes contacted with and its corresponding minimum hop-count value.

Step 2, this step starts when the flooding phase is terminated. This stage consists of computing the range distance by hop for each anchor. It is the average distance of hops called hop-Size based on the distance between anchors and the minimum number of hops. More accurately, the calculation formula of the hop-size for an anchor i is calculated according to the following 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_{ij} is the minimum hop count between anchor i and j and n records the total number of anchors connected by node i, (x_i, y_i) and (x_j, y_j) are the positions of anchor nodes i and j respectively. Next, each anchor node notices its hop-size to the rest of the nodes in the network. This permits the unknown nodes to calculate the distance to all their attainable anchor nodes. Considering the unknown node k following this formula (2) to calculate its distance from the anchor i.

$$d_i = HopSize_i \times h_{ki} \tag{2}$$

where $HopSize_i$ is the range distance per hop for anchor i and h_{ki} is the minimum number of hop-count between node k and anchor i. Step3, Once the average distance of hops is known, the determination of the unknown node position is launched using the multilateration method. The set of the equations presented by the following system formulates the multilateration method:

$$\begin{cases} (x_1 - x_k)^2 + (y_1 - y_k)^2 = d_{1k}^2 \\ (x_2 - x_k)^2 + (y_2 - y_k)^2 = d_{2k}^2 \\ \cdots \\ (x_N - x_k)^2 + (y_N - y_k)^2 = d_{Nk}^2 \end{cases} \tag{3}$$

where (x_i, y_i) (i = 1,2,...N) is the location of anchor node i, d_{ik} is the valued distance segregating an anchor i from the unknown node k which is obtained by Equation (2). the expansion of the Equation (3) done by the subtraction of the $(N-1)$ equations from the last equation of the system (3) conducts for a system containing $N-1$ equations.

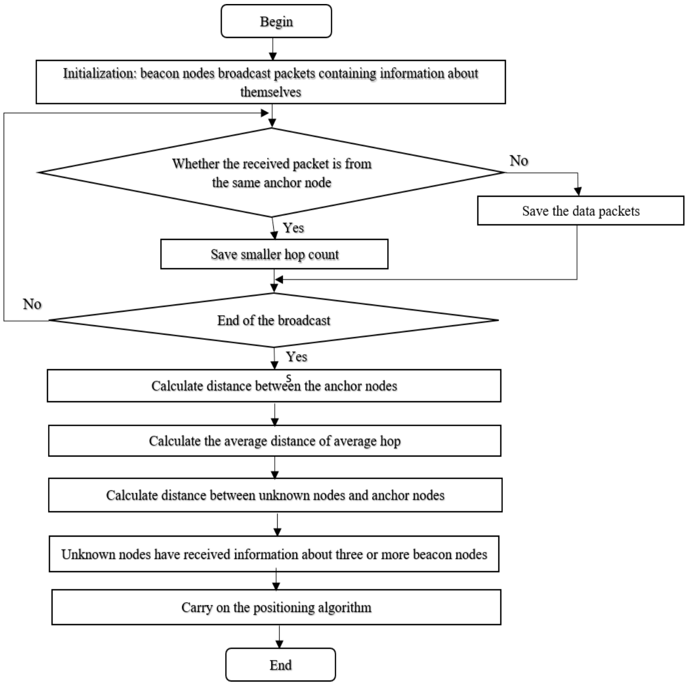

Fig. 2. The entire flowchart of the traditional DV-Hop algorithm

Then, converting this system of equations into a matrix form defined as follows

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

we designate the X=(x_k, y_k) , And

$$A = 2\begin{bmatrix} (x_1 - x_N) & (y_1 - y_N) \\ (x_2 - x_N) & (y_2 - y_N) \\ .. & .. \\ (x_{N-1} - x_N) & (y_{N-1} - y_N) \end{bmatrix} \tag{5}$$

$$B = \begin{bmatrix} x_1^2 - x_N^2 + y_1^2 - y_N^2 + d_{Nk}^2 - d_{1k}^2 \\ x_2^2 - x_N^2 + y_2^2 - y_N^2 + d_{Nk}^2 - d_{2k}^2 \\ .. \\ x_{N-1}^2 - x_N^2 + y_{N-1}^2 - y_N^2 + d_{Nk}^2 - d_{(N-1)k}^2 \end{bmatrix} \tag{6}$$

Finding the location of the unknown node k could be calculated by solving the equation (4) using the least square method. The following expression is presented the solution

$$X = (A^T A)^{-1} A^T B \tag{7}$$

The general entire flowchart of the traditional DV-Hop algorithm is described in Fig. 2.

B. Error Analysis of the Original DV-Hop Localization Algorithm

In this step, the error of localization is caused owing to the calculation of the average distance per hop, hop-size, by each anchor. Citing an example illustrated in Fig.3 of WSN network topology containing three anchor nodes A1, A2, A3, and unknown nodes Ui where i from 1 to N. After the first

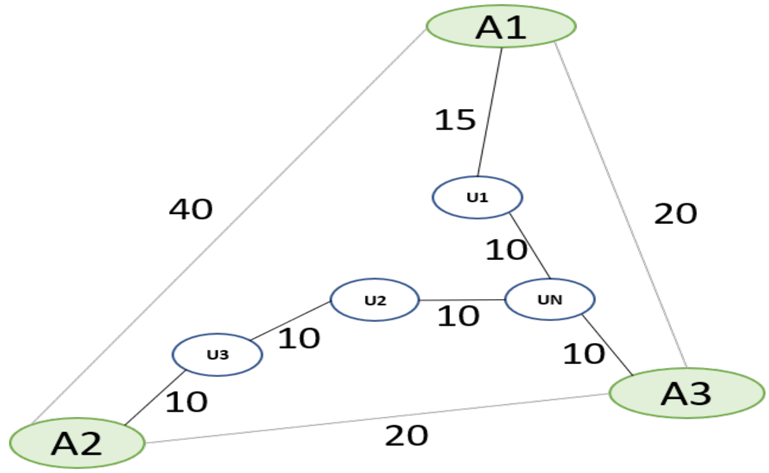

Fig. 3. Node distrubition model

step, each anchor node is aware of its location and its minimum hops from each unknown node. The black line connecting two nodes notify the direct communication transfers between them. Therefore, the communication range of each sensor is 10m and the distances between anchors are 20, 20, 40m from A3 to A1, A3 to A2, and A1 to A2 respectively. Also, 3, 5, 4 are the number of hops between A1: A3, A1:A2, and A3:A2 respectively. The average hop-size of the three anchors in this network is calculated as follows using the original DV-Hop algorithm, Equation(1).

$$HA_1 = \frac{40+20}{3+5} = 7.5 \tag{8}$$

$$HA_2 = \frac{40+20}{5+4} = 6.666 \tag{9}$$

$$HA_3 = \frac{20+20}{3+4} = 5.714 \tag{10}$$

As well, the number of hops from UN to A1, A2, A3 is 2, 3, 1 respectively. Then, the distance estimated by the Dv-Hop algorithm between the unknown node UN and the anchor 3 is 1 $\times$ 5.7=5.7m using Equation(2). However, in the outline, we can notice that the real distance between A3 and the unknown node is 10 which proves the huge error made by the method of calculating the average of hop sizes by anchors and to demonstrate how far the results are.

IV. Improved Least-Square DV-Hop Algorithm

The localization accuracy depends on the accuracy of the estimated average distance per hop. In this section, we will represent the scope of improvements in the second phase of the DV-Hop by the least-square proposal. We will focus on improving the accuracy of the large error that occurred in the second stage of the original DV-Hop algorithm. The aim of the amelioration is the Computation of the Optimal Average HopSize by every anchor. The more this hop-size is precise, the more the estimated distances are accurate.

For the second stage of the traditional Dv-Hop algorithm, we adopt a new proposal to calculate the average hop-size between anchors by applying the least square method [16] instead of the original technique. In our method, we elaborate on square calculation of the distances and hops presented by the following relationship so that we minimize the localization error in the third stage where we calculate the positions of the unknown nodes by the multilateration method.

$$\sum_{j=1}^{Na} hopA_{ij}^2 \cdot a_{ji} = dA_{ij}^2 \tag{11}$$

i:1..Na, j:1..Na where Na is the number of anchors, $hopA_{ij}$ represents the minimum number of hops between anchor nodes, dA_{ij} represents the distances between anchor nodes and a_{ij} represents the hop-size between anchor node i and anchor node j. Also,

$$\alpha = [a_{ij}] \tag{12}$$

We state the following linear relational matrix equation and we seek to determine the hop-size factor between anchors.

$$HA \times \alpha = DA \tag{13}$$

where HA, DA represent the square of anchor hops and the square of the distances between anchors respectively.

The matrix DA represents the square of the distances dA_{ij} between anchor i and anchor j computed by the following equation :

$$dA_{ij} = \sqrt{(x_{aN_i} - x_{aN_j})^2 + (y_{aN_i} - y_{aN_j})^2} \tag{14}$$

According to the data of anchor nodes, we calculate the parameter α using the Least Square model to solve the linear equation (13). As well, the solution is obtained by the formulation follow

$$\alpha = arg_{\alpha}\ \ min||HA \times \alpha - DA||^2 \tag{15}$$

where $||.||^2$ is the Euclidean norm. Here is the solution to the above least square problem :

$$\alpha = HA^{\dagger} \times DA \tag{16}$$

where

$$HA^{\dagger} = (HA^T HA)^{-1} HA^{^T} \tag{17}$$

Furthermore, α would be described as following

$$\alpha = (HA^T HA)^{-1} HA^{^T} DA \tag{18}$$

For the anisotropic WSN, we shall improve the solution based on the generalization performance considered by the distance error estimated between the nodes. The most important thing in our method is to minimize the square of localization error and the α vector norm. For that, the Regularized Least Squares (RLS) model is necessary to solve the least square problems by adding a regularization item to the model. The following function presented the proposed model:

$$\alpha = arg_{\alpha}\ \ min||HA \times \alpha - DA||^2 + k||\alpha||^2 \tag{19}$$

where $||.||^2$ is the Euclidean norm and k is the regularization parameter of the least square solution. Then, the generalized solution for the Hop-size α is presented as follows:

$$\alpha = (HA^T HA + kI_d)^{-1} HA^{^T} DA \tag{20}$$

where I_d is the Identity matrix and k is a constant to be adjusted during the simulation process.

Then, we aim to compute the distances of unknown nodes from anchor nodes through the weighting α hop-size average received by the minimum hops and their corresponding distances calculated for anchors. For the unknown nodes, we consider the relationship between HN the square of the number of hops matrix and DN to find the square of the estimated distances by the next linear equation:

$$HN \times \alpha = DN \tag{21}$$

where HN is a square hop-count matrix between the unknown sensor nodes and anchor nodes with dimensions $Nn \times Na$ and Nn is the number of unknown nodes.

Accordingly, the solution of the polynomial function (21) can be given using the hop-size solution calculated for anchors (20) to find the distance estimation DN between anchors and unknown nodes .

Here, by solving the former we get the generalized solution of our proposal for the distance between nodes as follows

$$DN = HN(HA^T HA + kI_d)^{-1} HA^{^T} DA \tag{22}$$

Later by applying the method of trilateration [17], we obtain an estimation of the unknown node coordinates by the transformed set of equations linked to the estimated distances between the unknown nodes and anchor nodes.

V. Experimental results and analysis

In this section, we assess the performance of our suggested algorithm. We use Matlab software to implement and simulate our algorithm. To get the average localization error for different situations in the isotropic cases, we simulate many times our algorithm by generating the nodes' deployment in the network then we evaluate the average errors in each case.

A. Localization results

For our simulations, we consider an isotropic field with 100×100 meters where the sensor nodes are randomly deployed in the sensing area. The communication range of each node is 20 meters. The localization results for 300 sensor nodes (30 anchors and 270 Unknown nodes) are shown in Fig.4.

Green diamonds mark anchor nodes and blue circles mark the real position of the unknown node. The red straight lines represent the estimation error of localization. As it is observed in figure.4, the area where the anchor nodes decrease the localization error increases .

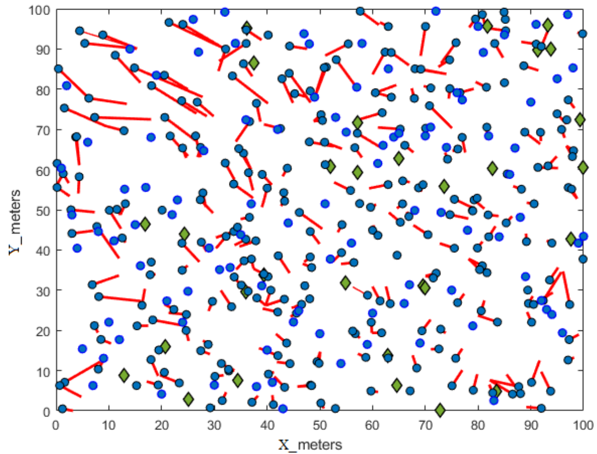

Fig. 4. Localization result for 300 sensor nodes deployed randomly

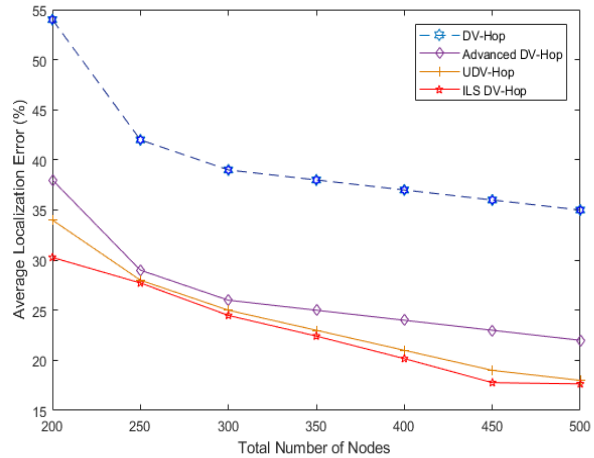

Fig. 5. Total Number of Nodes regarding Localization Error

B. Localization error analysis

The localization accuracy defined generally to evaluate the performance of any localization algorithm by estimating the error parameter as expressed in the following formula:

$$Error = \sum_{i=1}^{n} \frac{\sqrt{(X_i - x_i)^2 + (Y_i - y_i)^2}}{n \times R} \tag{23}$$

where $(X_i, Y_i\ )$ the estimated coordinates of the i^{th} unknown node and (x_i, y_i)the real coordinates for that node. R is the range of communication and n is the number of the unknown nodes. Therefore, from this expression (23) we deduce that the localisation accuracy depends on some parameters which are the range of communication, the number of the unknown nodes and the number of anchors. In the following experiments, we use the same sensor network topology to apply our algorithm with successively variation of one of these parameters to make a clear comparison with the original DV-Hop, UDV-Hop and the Advanced DV-Hop algorithm about the localization accuracy.

1) Nodes amount variation: In the first essay, we assess our developed algorithm ILS DV-Hop performance and then we compare it with the original DV-Hop algorithm, UDV-Hop algorithm [18], and Advanced DV-Hop [19]. The evaluation will be based on the localization accuracy results. For this experiment, all the nodes (anchor nodes + unknown nodes) are randomly deployed in the sensing area with an amount varying from 200 to 500 where 10% of this amount is toward anchor nodes and for a communication range equal to 15 meters. Fig.5 shows the results of these algorithms in terms of the localization error varied with the total number of nodes, we take notice that the increase of the total nodes positively affects the localization error by an important decrease. This is logically explained by the rise of connectivity in the network. Along with this dense connectivity, the average distance between anchors and unknown nodes becomes more accurate. By analyzing the Fig.5, the localization accuracy of our algorithm improved compared with this concurrent algorithms. In fact, the localization error is less about 25%, 8%, 4% than the original DV-Hop algorithm, Advanced DV-Hop algorithm and UDV-Hop algorithm respectively.

2) percent of anchor nodes variation: For the second essay, we consider our trial network containing 300 sensor nodes (Anchor nodes + Unknown nodes) randomly deployed in the sensing field where the percentage of anchor nodes varies from 5% to 30% and for a communication range equal to 15 meters by all the sensors. The results of this experiment are plotted in Fig.6 by presenting the average localization error regarding the variation of anchor nodes amount. It is clear the decrease of the localization error while increasing the number of anchor nodes. This is explainable by the fact that the unknown nodes can receive information from more anchor nodes which helps to improve the distance estimation between the unknown nodes and their nearest anchors by decreasing the number of hops between the unknown nodes and their anchors. Thus, as is shown in Fig.6, our algorithm ILS DV-Hop has the best performance compared to its coexistent algorithms in this literature. As we can see, for 30% of anchor nodes, the localization error of our proposed algorithm is less than 17% while the error percentage range starts from 18%, 20%, to 36% for the rest of mentioned algorithms.

3) Communication range variation: For the last essay, we consider the experiment within a sensing field containing 300 sensor nodes (Anchor nodes + Unknown nodes) that deposit randomly in the network. The anchor nodes amount is 10% of the total amount of nodes. In Fig.7, we have varied the communication range to appraise the localization accuracy. In effect, the average localization error decreases while the communication range increases. We can clear up this result by the fact that the network becomes more connected. This is due to the augmentation of the communication while conserving the same number of unknown nodes and anchor nodes. Therefore, the number of neighboring anchors for each unknown node increases which positively affects the localization accuracy by

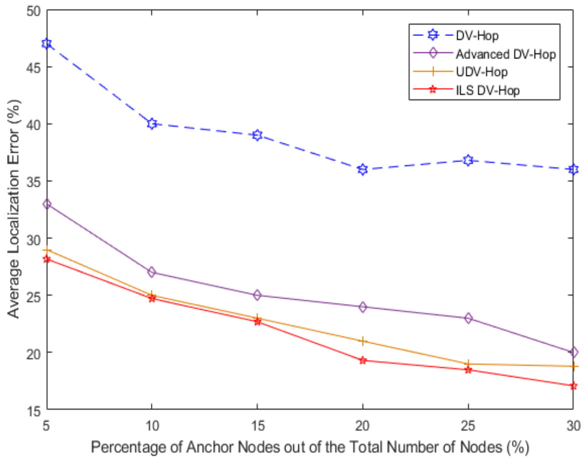

Fig. 6. The average localization error regarding the variation of anchor nodes amount

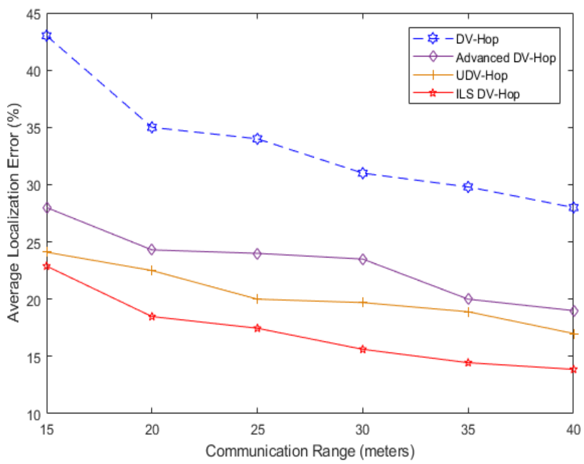

Fig. 7. The average localization error regarding the variation of the communication range

decreasing the localization error. Otherwise, the localization error achieves less than 14% for our proposed algorithm when the communication range is equal to 40 meters. For the same range of communication value, the counterparts algorithms have a more important percentage of the localization error upper of 14%, 5% and 2% than our proposed algorithm by the original DV-Hop algorithm, Advanced DV-Hop algorithm and the UDV-Hop algorithm respectively.

VI. Conclusion

In this paper, we aim to improve the localization accuracy for sensor nodes randomly distributed in a large scale wireless sensor network. Our proposed algorithm is based on regularization of the least square method, ILS DV-Hop algorithm (Improved Least Square DV-Hop algorithm) which is based on the improvement of the original DV-Hop by the optimization of the hop size by exploiting the regularized least square approximation. Based on the simulation results, our proposed achieves a high level of localization accuracy compared with the original DV-Hop, the Advanced DV-Hop and the UDV-Hop algorithms mentioned in the literature.

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