Improved DV-Hop Localization Algorithm for Wireless Sensor Networks

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Abstract - Wireless sensor networks (WSN) are usually composed of a great number of randomly deployed nodes that communicate among themselves and gather information about the environment. In many applications, it is required to know geographical location of the sensor which detected an event. The existing localization algorithms can be classified into two categories: range-based and range-free. Range-based algorithms measure the actual distances between nodes, while range-free algorithms approximate the distance based on connectivity information. Range-free localization is cost-effective alternative to a more expensive range based approaches since there is no necessity for additional hardware. However, these techniques usually have higher localization error compared to the range-based algorithms. DV-Hop is one of the range-free localization algorithms utilizing hop-distance estimation. In this paper, we propose an improvement of the range-free DV-Hop localization algorithm and present simulations results to evaluate it.

Keywords: Range-free, Localization, Wireless sensor networks, DV-Hop, Anchors

I. INTRODUCTION

Localization problem plays an important role in WSN. It is a great challenge due to limited resources. In many applications of WSN it is necessary to know node position, for example in routing protocols [1]. The easiest way to determine node location is by using GPS (Global Positioning System). But it has several drawbacks: expensive method (large number of nodes and limited power source), inaccurate in indoor environment, too expensive to be used in large scale WSN etc.

Many algorithms were developed to solve this problem. The localization algorithms can be divided into two categories: range-free and range-based [3] [4] [6]. Range-free localization algorithms are based on connectivity information of the nodes. They do not rely on any additional hardware which makes them cost-effective. Range-based localization depends on the assumption that the absolute distance between a sender and a receiver can be approximated by the received signal strength or by the time-of-flight of the communication signal from the sender to the receiver. The accuracy of such estimation is subject to the transmission medium, surrounding environment and usually relies on a complex hardware [10].

If some limited number of nodes is equipped with GPS, others can position themselves based on the connectivity information with these nodes. These nodes are usually called “anchors”, and they can be mobile or static. Anchors broadcast their location into the network, and other nodes can estimate self-position based on the hop counts from the anchors. Approximation of distance is critical in this method and it requires dense and uniform network to be accurate. The higher the hop count, the higher the estimated distance error.

In this paper, the improvement of the unknown node location estimation is considered by adding some additional steps to the DV-Hop algorithm [3]. After obtaining the unknown coordinates using DV-Hop algorithm, the following localization method is proposed. The unknown nodes have the information about distances from all anchors, measured in a number of hops. In the further calculations only the nearest anchor position measured in the number of hops is used, and this will be the first reference point.

To obtain the additional two reference points, two circles are formed. The first one is with the center positioned to this anchor position (radius corresponds to the estimated distance derived from the DV-Hop). The second circle center coordinates are obtained by the DV-Hop (radius corresponds to the Euclidian distance between the anchor and unknown node coordinates obtained by the DV-Hop). The two circles have two intersection points which can be calculated and used as two additional reference points.

There are three reference points now, and the final coordinates (that incur a lower localization error) of the unknown node is calculated using a centroid of the triangle that form these reference points. The exact explanation of the proposed algorithm (designated as iDV-Hop) is explained in the section IV.

The rest of the paper is organized as follows. In section II literature review is given. Section III describes the DV-Hop algorithm. Simulation results are given in the section V before concluding remarks.
II. LITERATURE REVIEW

The existing localization algorithms can be classified into two categories based on either it is required to measure the actual distances between the nodes or approximate it based on the connectivity information. There are range-based and range-free algorithms.

The range-based algorithms require distance or angle information between neighboring nodes to determine the location using trilateration. Some examples are: ToA [10] (Time of Arrival), TdoA [12] (Time Difference on Arrival) [11], AoA (Angle of Arrival) and RSSI (Received Signal Strength Indicator) [13].

ToA measures the distance between nodes using signal propagation time. In TdoA, the inter-node distance is determined based on the difference in propagation times of radio and acoustic signals originated at the same point. AoA technique locates the position by estimating and mapping relative angles between neighbors. RSSI is one of the simplest localization methods that is broadly used in many fields. It utilizes the fact that the energy of the radio signal decreases as it propagates in space. According to the intensity of the received signal, the attenuation is measured and the distance to the sender is calculated. The accuracy of RSSI measurements is highly sensitive to multipath, fading and other sources of interference, which may result in additional errors.

Range-based algorithms have higher accuracy compared to range free, but require additional hardware and hence the overall hardware cost is too high to be used in large scale networks.

DV-Hop localization scheme proposed by Nicolescu and Nath [3] is similar to the traditional routing schemes based on the distance vector. Each node first counts the minimum hop number to the anchor node and then computes the distance between the node and the anchor node by multiplying minimum hop number and average distance of each hop. The node estimates its position using triangulation algorithm or maximum likelihood estimators (MLE).

He et al. proposed an approximate point-in-triangulation test (APIT) algorithm in [4]. Using three anchors, APIT employs area-based method to estimate node position.

Amorphous algorithm is similar to the DV-Hop, but it assumes that the network density is known in advance, and uses offline hop-distance estimations [12]. It proposed a generation of a relatively accurate coordinate system on distributed processors via local information. Triangulation is also used to estimate a node’s location.

Centroid algorithm is a simple range-free localization algorithm [2] [5]. The node receives signals of landmarks in its communication area and makes its coordinates as the centroid of these landmarks. Additional devices of localization are not required in this algorithm. Therefore, the hardware of the nodes can be simple. Centroid, DV-Hop, Amorphous, and APIT are distributed algorithms.

Based on the properties of the DV-Hop, an improved scheme was proposed by Chen et al. in wireless sensor networks [7]. Main principle is to estimate distance of the hops according to the number of the neighbors in the same block. To reduce the localization error, it uses weighted node distances to compute the node's final coordinates.

Yi et al. put forward an improved positioning algorithm based on the DV-Hop algorithm [8]. It features a differential error correction scheme, in which average per hop distance of the position network and modified value of distance error are introduced to reduce cumulative distance error and node location error accumulated over the multiple hops. The main drawback of this algorithm is high computation and communication overhead.

In [16], an improved DV-Hop scheme (named NDV-Hop_Bon) is proposed, the main idea is to select a certain number of anchor nodes, instead of all. Due to only selecting the anchor nodes with the short distance, this new localization algorithm achieves a minimum positioning error by selecting the number of optimal anchor nodes. The performance evaluation is conducted on a medium scale WSN. It still has the limitation depending on the application. When the anchor node’s energy is too low, the positioning accuracy cannot meet the requirements. Communication cost is increased due to additional computation of the optimal number of anchor nodes.

In [17], another improvement of the DV-Hop is presented. It focuses on the correction of the hop-size. After calculating the hop-size, anchor node broadcasts it to the network with correction. Corrected hop-size is average of all anchor nodes hop-sizes. Instead of using the traditional triangulation, 2-D Hyperbolic localization algorithm is implemented for calculating the final position of the node. Simulation results showed that new algorithm can improve accuracy, but achieves less coverage.

There are still further possibilities to improve the DV-Hop algorithm in terms of lower localization error.

III. DV-HOP LOCALIZATION ALGORITHM

In the DV-Hop algorithm is assumed the following:

1) all nodes in the network acquire the minimum hop count values to all anchors using flooding (anchors are the reference nodes).

2) the average single hop distance is estimated to convert hop count value into physical distance. For the anchor node with (x, y) coordinates, the average distance per hop is estimated by the following equation:
where \((x_j, y_j)\), is the location of the anchor \(j\), \(h_{ij}\) is the number of hops between the anchor node \(i\) and the anchor node \(j\). Once calculated, the estimated \(\text{HopSize}_i\) information is broadcasted into the network.

3) the unknown node location can be estimated by the multilateration method when these nodes have the distance estimations to at least three anchors. Given a set of reference nodes \(N_i (x_i, y_i)^T, i = 1 \ldots n\), where \(n\) is the number of anchors, let the hop value between the unknown node \(X(x, y)^T\), and the \(i\)-th anchor is \(R_i\). Then the distance between the unknown node and \(i\)-th anchor node is given by \(d_i = R_i \cdot \text{HopSize}_i\). The unknown node location \(X\) can be found from:

\[
\begin{align*}
(x_1 - x)^2 + (y_1 - y)^2 &= d_1^2 \\
(x_2 - x)^2 + (y_2 - y)^2 &= d_2^2 \\
& \ldots \\
(x_n - x)^2 + (y_n - y)^2 &= d_n^2
\end{align*}
\]  

(2)

Equation (2) can be written in matrix form \(AX = b\) where:

\[
A = \begin{bmatrix}
2(x_1 - x_n) & 2(y_1 - y_n) \\
2(x_2 - x_n) & 2(y_2 - y_n) \\
& \ldots \\
2(x_{n-1} - x_n) & 2(y_{n-1} - y_n)
\end{bmatrix}
\]  

(3)

\[
b = \begin{bmatrix}
x_1^2 - x_n^2 + y_1^2 - y_n^2 + d_1^2 - d_n^2 \\
x_2^2 - x_n^2 + y_2^2 - y_n^2 + d_2^2 - d_n^2 \\
& \ldots \\
x_{n-1}^2 - x_n^2 + y_{n-1}^2 - y_n^2 + d_{n-1}^2 - d_n^2
\end{bmatrix}
\]  

(4)

\[
X = \begin{bmatrix} x \\ y \end{bmatrix}
\]  

(5)

The least-squares estimate of \(X\) is \(X = (A^T A)^{-1} A^T b\).

IV. THE iDV-HOP ALGORITHM

Main disadvantage of the traditional DV-Hop, is that the accuracy of the algorithm is affected by the distances between the unknown nodes and the anchor nodes. As mentioned in the section II, distance estimation leads to high localization error as number of hop counts increase or with rise of the network irregularity. We use the DV-Hop algorithm to calculate the initial position, and propose to use the following additional steps forming our iDV-Hop algorithm:

Step 1.) For unknown node \(X_i\) with estimated coordinates \(x_i, y_i\) in final step of the DV-Hop, choose an anchor that is minimum number of hops away, denoted as \(A_i(x_i, y_i)\).

Step 2.) Form two circles, one around anchor \(A_i\) and other around node \(X_i\), denoted as \(C_i\), and \(C_j\), respectively. Radius \(R_i\) is equal to the distance between the node \(X_i\) and the anchor \(A_i\). If \(\text{HopSize}_i\), obtain by the (1) average per-hop distance, then the radius \(R_i\) of the second circle is calculated by the (7). Here, \(\text{hop}_{ij}\) is minimum number of hops between the anchor \(A_i\) and the unknown node \(X_j\).

\[
R_i^2 = (x_i - x_j)^2 + (y_i - y_j)^2
\]  

(6)

\[
R_i = \text{HopSize}_i \cdot \text{hop}_{ij}
\]  

(7)

Step 3.) Find the intersection points of these two circles (\(C_i \cap C_j\)). These points are denoted as \(S_i(x_{si}, y_{si})\) and \(S_j(x_{sj}, y_{sj})\). Finally, the unknown node coordinates are calculated according to following centroid formula:

\[
X_i^T = \frac{x_i + x_j + x_{si} + x_{sj}}{4}, \quad \frac{y_i + y_j + y_{si} + y_{sj}}{4}
\]  

(8)

Equation (8) basically represents centroid of the triangle that form the anchor and the two intersection points (see Fig. 1).

V. SIMULATIONS AND RESULTS

To validate the iDV-Hop algorithm, thorough simulations are performed. The simulation result is given as average localization error of 100 experiments. The localization error is analyzed in various environments, influence of different parameters and compared with the DV-Hop and Improved DV-Hop proposed in [17]. The placement of the anchor nodes has a high impact on the algorithm, thus two scenarios with four types of topology are considered, random uniform, gridy uniform, C shaped random uniform and C shaped gridy uniform. The localization errors are represented by the ratio of the Euclidean distances between estimated coordinates and actual nodes coordinates, scaled to the communication radius \(R\).
The simulation parameters are the following:

1. All nodes are static (there are no mobile nodes)
2. Network topology is gridy uniform, C shaped gridy uniform, random uniform, C shaped random uniform
3. Network size is 50 x 50m
4. Number of anchors Na = 3-25 for gridy and C shaped gridy topology, Na = 3-20 for random and C shaped random topology
5. Transmission range \( R = 6-15m \) for gridy and C shaped topology, \( R = 12-20m \) for random and C shaped random topology

In the gridy uniform scenario called gridy since the position of the nodes deviates from the exact position in the orthogonal grid), anchors and nodes are uniformly distributed (with some placement error); 90 sensor nodes are deployed and 6 anchors (see Fig. 2). Fig. 3 illustrates random uniform node placement. Fig. 4 and 5 illustrates C shaped gridy and C shaped random topology, respectively.

Localization error as a function of the radio transmission range is given for gridy and random scenarios in Fig.6 and Fig.7. It is depicted in the Fig.6 that for the same transmission range, e.g., \( R = 6m \), DV-Hop and Improved DV-Hop the localization error (scaled to \( R \)) is around 1.3\( R \), while the iDV-Hop is around 1\( R \).

As depicted in the Fig.6, the localization error decreases with the increase of the transmission range, but after around \( R = 6.5m \) DV-Hop and Improved DV-Hop achieves better performances. Thus, with minimum communication range (in our simulation \( R = 6m \)) iDV-Hop algorithm reduced the localization error by around 25% compared to the DV-Hop and Improved DV-Hop algorithm. Initially, iDV-Hop is better, to some limited range. With the increase of the communication range (the network connectivity rises), the estimated hop-distance is closer to the Euclidean distance between two sensor nodes, thus lowering the localization error.
In the random uniform placement scenario, the iDV-Hop algorithm achieves lower error. (see Fig.7). Herein, the number of the anchors and the unknown nodes is fixed to 5 and 50, respectively. As depicted in the Fig. 7, the error decreases gradually from around 1.1R to around 0.85R with the increase of the transmission range for the iDV-Hop algorithm, for DV-Hop and Improved DV-Hop it is in level of error between 1.2R and 0.95R.

The localization error decreases as the number of anchor nodes increases, as can be seen in Fig.10 for gridy placement. For the minimal number of anchors (Na = 3) localization error of the DV-Hop is around 1.6R for the gridy placement and for iDV-Hop algorithm it is around the same. (see Fig.10). With a maximal number of anchors (Na = 25), the error is close to 1R for algorithm and 1.4R for DV-Hop. In case of Improved DV-Hop with the increase of a number of anchors performances are worse than iDV-Hop and DV-Hop for gridy topology. For the same number of anchors e.g., Na = 10, the localization error for iDV-HOP is around 1.1R, while DV-Hop is around 1.35R and for Improved DV-Hop is higher (1.5R) than original algorithm and method proposed in this paper.

With the increase of a number of anchors our algorithm achieves lower localization error. This means that iDV-Hop can reduce error by around 20% on average in case of gridy topology, compared with DV-Hop. In case of Improved DV-Hop the localization error is reduced by around 27%.

For the random topology scenario, the DV-Hop algorithm localization error as a function of the number of anchors decreases from 1.1R to around 0.8R (see Fig.11). The number of anchors were varied with fixed R = 12m and number of unknown nodes equal to 50. The error in estimating location for iDV-Hop decreases from 1R to approximately 0.7R. The localization error decreases with the increase of a number of anchors for all three algorithms, but performances of proposed method are better than DV-Hop and an Improved DV-Hop. The localization error is reduced by around 10% on average compared to DV-Hop, and by around 5% compared to Improved DV-Hop.

In case of C shaped gridy topology, with the increase of the network radius, iDV-Hop achieves lower error than other two algorithms. Initially, the localization error is reduced by around 40%, in compare with DV-Hop and Improved DV-Hop. (see Fig.8). The average localization error is reduced by 20%.

For C shaped random placement, the network radius is increased from 12 to 20m (see Fig.9). Initially (until around 14m) iDV-Hop performed better than other two algorithms. For R>14m all algorithms has similar localization error.
As a number of anchors increases, the unknown node has more reference points that can be used to estimate its position. Fig.12 and Fig.13 show the influence of the different number of anchor nodes on the average localization error. With the increase of a number of anchors iDV-Hop algorithm achieves lower localization error for the C shaped random and gridy topology (see Fig.12 and 13). The localization error is reduced by around 40% on average for the C shaped gridy scenario and by around 20% on average for the C shaped random network, comparing with DV-Hop.

V. CONCLUSION

In this paper, the improvement of the range-free DV-Hop algorithm is proposed. Simulation results show that the iDV-Hop scheme is better compared to the original DV-Hop algorithm and an improved method proposed in [17] in terms of localization error. iDV-Hop with a minimal radius can reduce error for 25% in gridy placement and around 20% on average in terms of anchor nodes number. For random topology it also performed better (around 10% on average). In case of C shaped networks iDV-Hop outperforms DV-Hop and Improved DV-Hop. The average localization error can be reduced by around 20%, when measured as a function of transmission radius, and around 30% in term of a number of anchors. The Improved DV-Hop is less accurate for gridy and C shaped networks, it performs better in random topology, in compare with DV-Hop, but iDV-Hop outperforms both of them in C shaped scenarios.

iDV-Hop requires a small number of additional calculations added to the DV-Hop and it is the main cost for the gained benefit. The problem of node localization in WSN remains an important open research problem. In the future, work can be focused on more accurate modification of this algorithm. More neighbors near to the unknown node, besides anchors, can be included in localization to more precisely determine unknown node position.

ACKNOWLEDGEMENT

This work was partially financed by the project "Innovative electronic components and systems based on inorganic and organic technologies embedded in consumer goods and products", pr. num. TR32016, Serbian Federal Ministry of Science and Education.

Equipment resources to support this work were provided within the FP7 APOSTILLE project, no. 256615.

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