An Improved DV-Hop Localization Algorithm

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Abstract. This paper proposes two improved DV-hop localization algorithms named an Equal Sub-Area-Based DV-Hop (ESAB-DV-Hop) and Equal Sub-Area-Based DV-Hop with RSSI (ESAB-DV-Hop with RSSI) which achieve less error than an original algorithm. The two proposed algorithms are derived from the DV-hop method. The 1st one depends on dividing the network area into sub-areas and setting the nodes with unknown locations to calculate their positions from anchor nodes in the same sub-area and the 2nd one depends on dividing the network area into sub-areas and each node with unknown location calculates the distance between itself and other nodes using hop count number if they are not neighbor anchor nodes and RSSI if they are neighbor anchor nodes. Simulation results show that the localization accuracy of the Equal Sub-Area-Based DV-Hop (ESAB-DV-Hop) method is better than the original algorithm by 13.5 % and by 12 % compared to a recent algorithm that solves the same problem when the total number of the nodes equals 100, the communication range is 20 m and the anchors ratio is 10 %. The Equal Sub-Area-Based DV-Hop with RSSI (ESAB-DV-Hop with RSSI) method is better than the original algorithm by 17.5 % and by 16 % compared to a recent algorithm that solves the same problem when the total number of the nodes equals 100, the communication range is 20 m and the anchors ratio 10 %.

Keywords: Wireless sensor networks · Localization · DV-Hop

1 Introduction

Wireless sensor network has distributed nodes. These nodes send the data to the monitor base station. However, the monitor base station does not have correct view of the monitored area since those data are sent without any knowledge of the location where it is taken. In addition to that, GPS cannot be used in many applications as it consumes power and cannot be used in indoor applications. Many applications of wireless sensor networks are based on its position such as intrusion detection, inventory and supply chain management, and surveillance, environmental monitoring, indoor user tracking and so on. Therefore, localization is an important field of research for sensor networks that depends in its application on knowing sensors positions [1, 2].

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There are two main divisions of localization algorithms: range-based and range-free. Range-based method depends on the properties of the signals transmitted between neighboring nodes. There are many ranging techniques such as Time Of Arrival (TOA) [3], Time Difference Of Arrival (TDOA), Received Signal Strength Indicator (RSSI), and Angle Of Arrival (AOA) [4]. Range-free techniques estimate nodes locations based on connectivity information. Range-free algorithms do not require additional hardware [5]. There are many algorithms of range-free techniques such as Approximate Point In Triangulation (APIT) [6], Amorphous [7], Distance Vector-Hop method (DV-Hop) [2], Centroid method [8], and MDS-MAP [9, 10].

DV-Hop localization algorithm is a range-free technique. The main error source in DV-hop is that the real path distance between nodes does not reflect the calculated path distance because of the hop size value is not the same for all hops.

In this paper, we introduce an improved DV-hop technique to reduce the error and raise the accuracy of localization by dividing the area of the network into equal sub-areas, and each node with unknown location calculates its position from anchor nodes in the same sub-area. By this way, the hop size would be calculated from the anchor nodes in the same sub-area not the whole network.

Many approaches on wireless sensor network localization have been reported. Qian et al. proposed a modified DV-hop algorithm [11], which chooses specific anchors to find the position of the nodes with unknown locations. Ji and Liu proposed a modified DV-hop algorithm [12], which gets the value of hop size depending on communication radius of the node. Sassi, et al. selected 3 anchors including the nearest one from the node with unknown location depending on the more accurate position calculation results of this node with unknown location [13]. Yu and Li, proposed a method depending on adjusting the measured distance between the node with unknown location and Anchor node to be close from the real distance [17]. The previous works concentrate on decreasing the gap between the calculated hop size and the real distances between the nodes. Therefore, they can decrease the error of the position of unknown nodes.

The remainder of the paper is organized as follows: In Sect. 2, problem statement is mathematically represented and discussed and the form of the solution is given. In Sect. 3, the background of the original DV-Hop is introduced. Our Equal Sub-Area-Based DV-Hop and Equal Sub-Area-Based DV-Hop with RSSI is discussed in Sects. 4 and 5. In Sect. 6, simulation results and comparison are presented. Finally, in Sect. 7, the conclusion is presented.

2 Problem Statement

The problem of DV-hop is that the distance calculated from counting the hops between the node with unknown location and the anchors are not equal to the real distance between them, therefore, the number of hops does not reflect the actual distance. For example, as depicted in Fig. 1, the real distance between node U with unknown location and anchor node R1 is not equal the calculated distance (i.e., the size of the 2 hops between node U with unknown location and the anchor node R1). Therefore, decreasing the error of the calculated distance is the way to decrease the error of DV-hop and improve its accuracy.

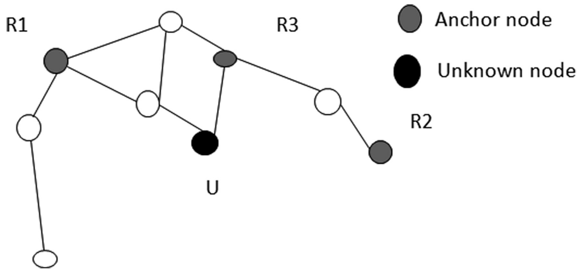

Fig. 1. Example of DV-hop algorithm

Our contribution proposes a modified DV-hop using 2 ways to decrease the error and increase the accuracy by using the 1st way which depends on dividing the area of the network into equal subareas, and each node with unknown location computes its position from its subarea's anchors and the 2nd way which also depends on dividing the area of the network into equal subareas, and each node with unknown location calculates the distance between itself and other nodes using hop count number if they are not neighbor anchor nodes and RSSI if they are neighbor anchor nodes. Using these 2 ways the hop-size will be calculated from the anchors' hop count in the same sub-area not in the whole network or will be calculated using RSSI from anchors' packets from the same sub-area. Hence, it reflects the real distance between nodes.

3 Dv-Hop Localization Algorithm

DV-Hop algorithm has been proposed by Niculescu and Nath [14, 15]. The original algorithm consists of three steps [1]:

1. Finding the shortest path between each anchor node and sensor nodes. Each anchor node broadcast message contains ID, position, hop count number. Each sensor node save the message with the minimum hop count to each anchor node and increment the hop count value by one then propagate the message. At the end of this stage, each node maintains routing table {ID, A_{xi}, A_{yi}, A_{hi}} where {A_{xi}, A_{yi}} is the location of node A_i and hop_{ij} is the minimum hop count number between sensor node and anchor node A_i.
2. Each anchor node finds the hop size value using the minimum hop count number hop_{ij} between it and the other anchors. Using this formula

$$hop\_size_i = \frac{\sum_{i \neq j} \sqrt{\left(A_{xi} - A_{xj}\right)^2 + \left(A_{yi} - A_{yj}\right)^2}}{\sum_{i \neq j} hop_{ij}} \tag{1}$$

Where (A_{xi}, A_{yi}), (A_{xj}, A_{yj}) are position coordinates of anchor A_i, and anchor A_j, hop_{ij} is the minimum number of hops between anchor $A_i$and anchor A_j. Then each anchor node propagates its estimated hop size value. Nodes with unknown locations receive the first one only to ensure it is the nearest anchor node. Then it calculates the distance between itself and the anchors by multiplying the hop size with the hop count.

When nodes with unknown locations have the distance of anchors, it computes its position coordinates using trilateration method which is a mathematical method used for finding the position of a node with unknown location using the distance between it and the anchors [2].

4 Proposed Equal Sub-Area Based DV-Hop

This paper proposes two methods to improve the localization accuracy. The 1st method depends on dividing the area of the network into equal sub areas, and each node with unknown location calculates its position from anchor nodes in the same sub-area. By this way, the hop size will be calculated from the anchor nodes in the same sub-area not in the whole network. The proposed method consists of the following steps (see flow chart in Fig. 2):

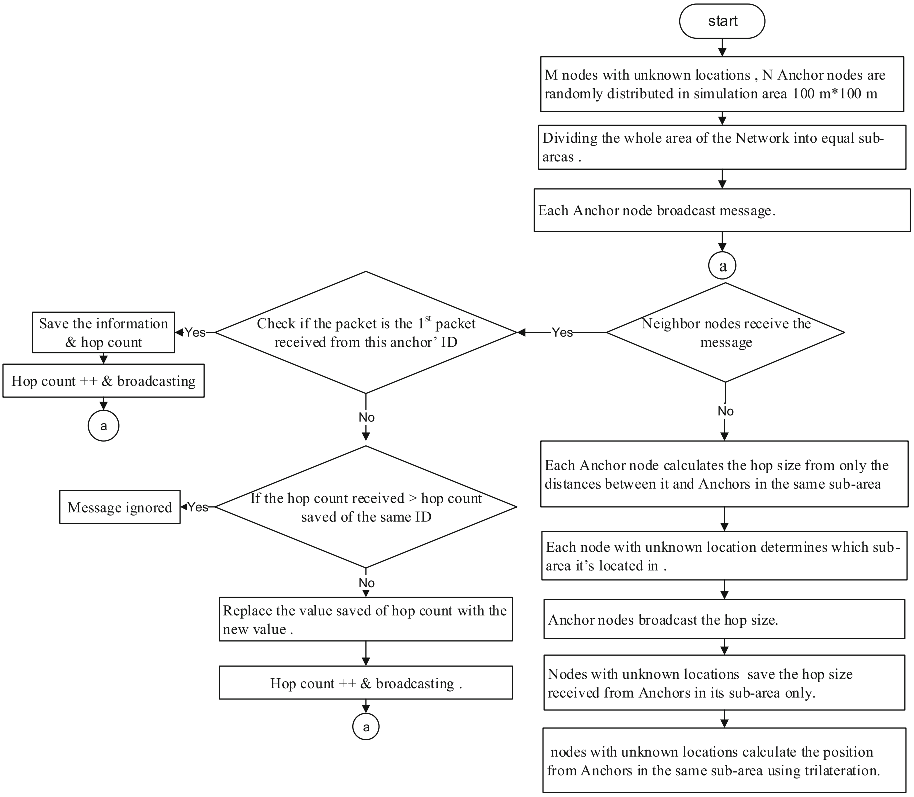

Fig. 2. Flow chart of the equal sub-area based DV-hop

1. Dividing the whole area of the network into equal sub-areas. The number of sub-areas is defined by:

$$Number\ of\ sub - areas(x) = Number\ of\ anchor\ nodes(y)/z$$

Where Z is the smallest number x divisible by it with condition that, it is equal to or more than three and it's the number of anchor nodes in each sub-area.

2. The difference in this step and step 1 in the original algorithm is that the message broadcasted by anchor nodes contains a new additional field for sub- area number to anchor packet, which represents a negligible overhead on the communications payload. Therefore, by the end of this stage, each node maintains a table $\{A_{xi}$, A_{yi}, sub-area number, $h_i\}$. Once an anchor A_i gets hop count value from other anchor nodes, it estimates the hop size from distances of anchors in the same sub-area not anchors over the entire network.
3. Each node with unknown location determines which sub-area it is located in by finding the smallest $\sum_{at\_specific\_sub-area} hop\_count$ of each anchor node to determine in which sub-area it is located.
4. Each node with unknown location uses the hop size to compute its position from anchor nodes in this sub-area using trilateration method [2]. This hop size is an average hop size received from anchors of the node with unknown location sub-area.

5 Proposed Equal Sub-Area Based DV-Hop with RSSI

The 2nd method depends on dividing the network area into sub-areas and each node with unknown location calculates the distance between itself and other anchor nodes using hop count number if they are not neighbors and RSSI if they are neighbor anchor nodes. By this way, the value of distances between node with unknown location and anchor node will be more accurate. The proposed method consists of the following steps (see flow chart in Fig. 3):

1. This step is similar to step 1 in the proposed Equal sub-area based DV-Hop.
2. The difference in this step and step 1 in the original algorithm is that the message broadcasted by anchor nodes contains a new additional field for sub- area number to anchor packet, which represents a negligible overhead on the communications payload. So, by the end of this stage, each anchor node maintains a table $\{A_{xi}$, Ayi, sub-area number, $h_i\}$ and each node with unknown position maintains table $\{A_{xi}$, A_{yi}, sub-area number, h_i, RSSI from anchors' neighbors to itself$\}$. Once an anchor A_i gets hop count value from other anchor nodes, it estimates the hop size from distances of anchors in the same sub-area not anchors over the entire network.
3. Each node with unknown position determines which sub-area it is located in by finding the smallest of each anchor node to determine in which sub- area it is located.

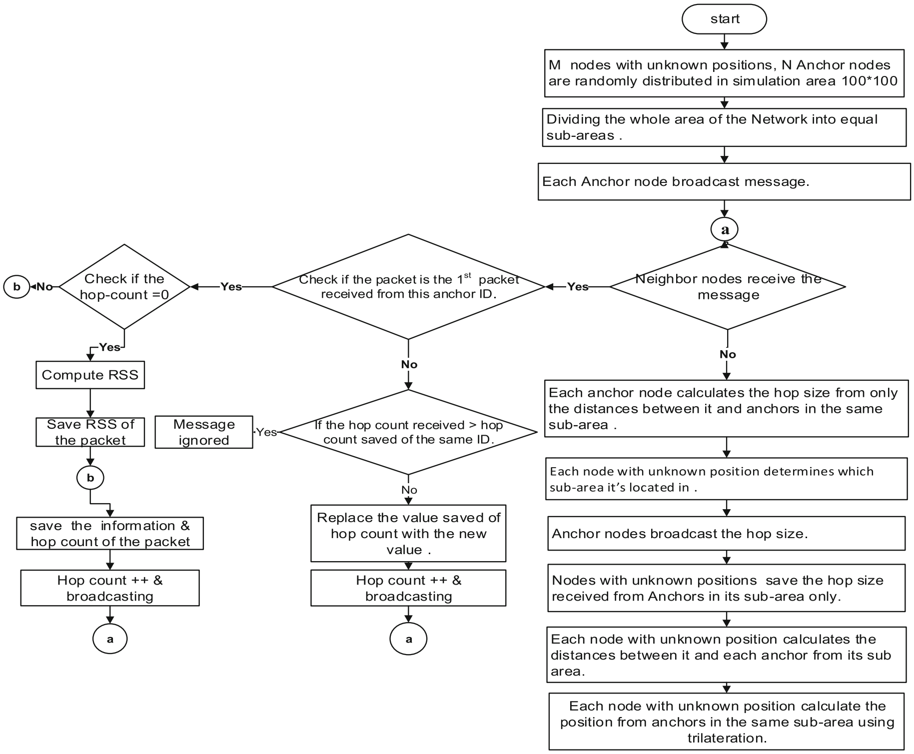

Fig. 3. Flow chart of the equal sub-area based DV-hop with RSSI

4. Nodes with unknown positions save the hop size received from Anchors in its sub-area only.
5. Each node with unknown position calculates the distances between it and each anchor from its sub- area. If the hop count between the node with unknown position and anchor node is one (i.e., its neighbor), it calculates the distance using RSSI. If the hop count between the nodes with unknown position and anchor node is more than one, it calculates the distance by multiplying the average hop size by the hop count.
6. Each node with unknown position calculates the position from anchors in the same sub-area using trilateration.

6 Performance Analysis and Comparison

In this section, the performance of the Equal Sub-Area-Based DV-Hop and Equal Sub-Area-Based DV-Hop with RSSI has been evaluated and compared with the traditional DV Hop and the recent research work of Yu and Li, [17]. Our developed algorithm has shown better localization accuracy than the improved dv-hop discussed in [17] using the same case studies.

Two *main scenarios* were foreseen for the performance analysis of the localization algorithm:

1st Scenario: All sensor nodes are randomly deployed in two dimensional area of *100* m**100 m.* The anchor nodes ratio is variable, while the total number of nodes is constant and equals 100 nodes. In the simulation, the localization error is defined as follows: assume the real coordinate of the node *Ui* with unknown location (*U*x*j*, *U*y*j*), and its estimated coordinates (*Uxi*, *Uyi*), *r* is the communication radius, the localization error is obtained as given in Eq. (2) [16]:

$$error_i = \frac{\sqrt{\left(U_{xi} - U_{xj}\right)^2 + \left(U_{xi} - U_{xj}\right)^2}}{r} \tag{2}$$

Figures 3 and 4 show the localization error when the total number of nodes equals 100 nodes with different ratios of anchors. As can be seen at a communication range of 20 m, Equal Sub-Area-Based DV-Hop has an average localization error about 39 % and Equal Sub-Area-Based DV-Hop with RSSI has an average localization error about 35 %. when the anchors ratio is 10 %, where the original DV-Hop has an average localization error about 52.5 % and the proposed method in [17] has an average localization error about 51 %. At a communication range of 25 m, The Equal Sub-Area-Based DV-Hop has an average localization error about 35 % and Equal Sub-Area-Based DV-Hop with RSSI has an average localization error about 32 %. Where the anchors ratio is 10 %, the original DV-Hop has an average localization error about 40 % and the proposed method in [17] has an average localization error about 38 %.

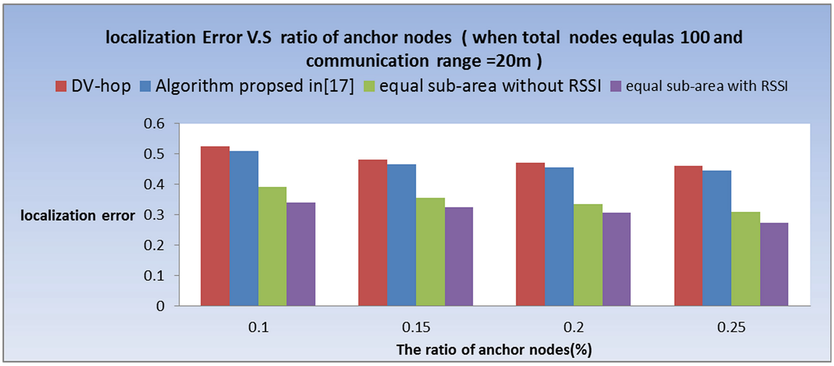

Fig. 4. The average localization error when the total nodes 100 node and the communication range 20 m.

2nd Scenario: The total number of nodes is variable while the anchor nodes ratio is constant.

Figures 5 and 6 show that the localization error when the anchors ratio is 10 % with different total number of nodes. As can be seen at a communication range of 20 m, Equal Sub-Area-Based DV-Hop has an average localization error about 29.58 % and Equal Sub-Area-Based DV-Hop with RSSI has an average localization error about 27 %. When the total number of nodes equals 200 nodes, where the original DV-Hop has an average localization error about 36 % and the proposed method in [17] has an average localization error about 33 %. At a communication range of 25 m, Equal Sub-Area-Based DV-Hop has an average localization error about 27.05 % and Equal Sub-Area-Based DV-Hop With RSSI has an average localization error about 24 %, when the total number of nodes equals 200 nodes, where the original DV-Hop has an average localization error about 33 % and the proposed method in [17] has an average localization error about 30.5 % (Fig. 7).

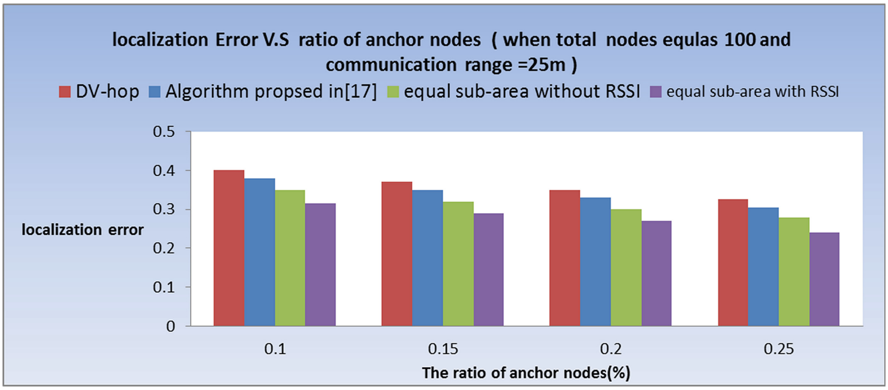

Fig. 5. The average localization error when the total nodes 100 node and the communication range 25 m.

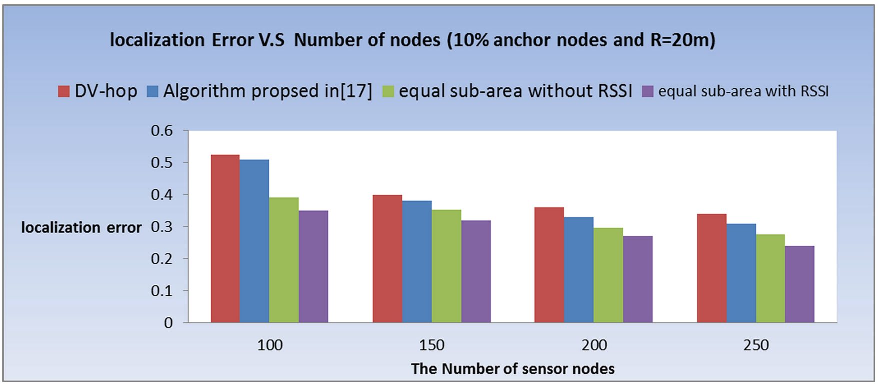

Fig. 6. The average localization error when anchors ratio is 10 % and the communication range 20 m.

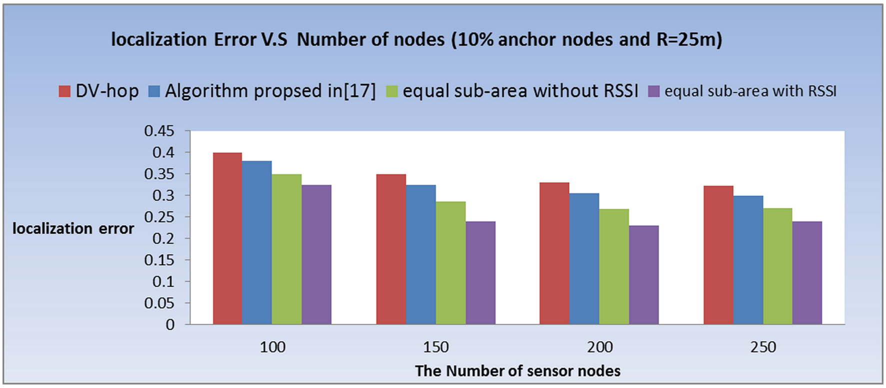

Fig. 7. The average localization error when anchors ratio is 10 % and the communication range 25 m.

7 Conclusion

In this paper, we introduce an Equal Sub-Area-Based DV-Hop method to achieve more localization accuracy. The idea behind our proposed method is to divide the network into equal sub-areas and each node with unknown location computes its position from anchors within its sub-area. Simulation results illustrate that the Equal Sub-Area-Based DV-Hop and Equal Sub-Area-Based DV-Hop with RSSI can decrease the localization error more than the traditional DV-hop method and proposed DV-hop in [17]. The simulation results show that the localization accuracy of the Equal Sub-Area-Based DV-Hop method is better than the original algorithm by 13.5 % and the proposed method in [17] by 12 % when the total number of the nodes equals 100, the communication range is 20 m and the anchors ratio 10 % and the Equal Sub-Area-Based DV-Hop with RSSI method is better than the original algorithm by 17.5 % and by 16 % compared to a recent algorithm that solves the same problem when the total number of the nodes equals 100, the communication range is 20 m and the anchors ratio 10 %.

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