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An Enhanced DV-Hop Localization Algorithm using RSSI

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Abstract

Localization has been identified as a key and challenging topic in Wireless Sensor Networks (WSNs), especially for the applications requiring the accurate position of the sensed information. DV-Hop is a typical range-free node localization algorithm in WSNs; the localization cost and hardware requirements are not high and localization accuracy of sensor nodes is still low under certain circumstances. Based on the main reasons of the error DV-Hop algorithm, an improved algorithm is proposed in this paper which reduces the location error without requiring additional hardware. The proposed algorithm uses Received Signal Strength Indicator (RSSI) to give the hop count a correction value. In the proposed algorithm the hop count is no longer positive integer number, and can be positive real number. With this new idea, the distance between sensor nodes can be more accurately computed that that of in DV-Hop localization algorithm. Since the distance between sensor nodes estimation is a key issue in localization for WSNs, the proposed algorithm achieves better performance as compared with DV-Hop algorithm. Simulations are performed and the results show that the enhanced DV-Hop algorithm outperforms the DV-Hop algorithm in term of localization accuracy.

Keywords: *wireless sensor networks; localization; DV-Hop algorithm; correction*

1. Introduction

Wireless sensor network (WSNs) are composed of a large number sensor nodes that cooperate among themselves to monitor an area of interest. Typically, the sensor nodes have limited computation, communication and power resources distributed in a designed area without any fixed structure [1]. Each sensor node is a small device that consists of data processing, sensing, and short range radio communication units, and a battery. WSNs are candidates for many applications such as border security, asset management, habitat monitoring, building automation as well as environment observation [2]. For most WSN applications, the location information of each sensor node is critical for the service. This is because users normally need to know not only what happens, but also where interested events happen or where the target is. In addition, location information could also aid in many location-aware sensor network communication services, such as packet routing and sensing coverage, tasking and querying. Unfortunately, it is impossible that every sensor node in WSN equipped with GPS to compute its location. Therefore, study on sensor node localization algorithm for WSN becomes one of the most important issues in WSNs researches. Although localization plays an important role in WSNs, it is a challenging problem because of the

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demanding requirements for low cost, high energy efficiency, and small footprint at the resource constrained sensor node side, as well as practical issues associated with network deployments.

Many localization algorithms for WSNs have been proposed to estimate the location of sensor nodes in literatures. According to whether there is a need for actual measurement of the distance between sensor nodes or sensor nodes' relative angle, existing localization algorithms in WSNs can the can be roughly classifieds as the ranged-based algorithms and range-free algorithms[2]. Their major difference lies in whether ranging-efforts are required at sensor nodes in WSNs. Range-based algorithm determines the location of unknown node by measuring the distance between adjacent senor nodes or locations of sensor nodes actually and has a high requirement of hardware because of the measurement of distance or angle between unknown node and reference nodes. These algorithms can be implemented by using the following physical measurement techniques: received signal strength indicator (RSSI) [3], time of arriving signal (TOA) [4], Time Difference of Arrival(TDOA)[5], and angle of arriving signal (AOA)[6]. In contrast, range-free algorithm mainly relies on network connectivity without measuring the distance between adjacent sensor nodes or locations of the sensor nodes actually. Therefore, they do not use additional costly hardware, which makes it more cost-effective and simpler alternative over range-base algorithms. Although range-free algorithms provide less accurate results compared with range-based algorithms, which is due to ranging errors, they satisfy many applications' requirements. Because of its cost-effectiveness and simplicity, the range-free algorithms have been drawn much attention for location in WSNs, such as Centroid method [7], DV-Hop (Distance Vector-Hop) method [8, 9], amorphous [10], APIT [11], MDS-MAP [12, 13], *et. al*.

In this paper, we introduce an improved DV-Hop algorithm for WSNs. The proposed algorithm improves location accuracy without increasing hardware cost and communication cost. We try to reduce the range measure error, which is the main cause of localization error of DV-Hop algorithms. In the proposed algorithms, we add correction to the hop count to enhance accuracy of range measure. The correction is depended on the RSSI, in which the sender's transmitting intensity can be known, and the receiver can compute the single loss after receiving message. RSSI is easy to be implemented and comparing with other ranged-based localization algorithms it doesn't need additional hardware as RSSI information can be obtained at almost no additional cost with each radio message sent and received

The remainder of the paper is organized as follows. In the next section, we give the overview of the DV-Hop algorithm and some existing improved DV-Hop algorithm. In Section 3, we describe the enhanced DV-Hop algorithm in detail. In Section 4, simulation study is conducted to evaluate our proposed algorithms. Finally, the conclusions are given in Section 5.

2. Related Works

2.1. Overview of the DV-Hop Algorithm

In this section we describe the DV-Hop algorithm [9, 10] in brief. The algorithm implementation consists of three stages. In the first stage, each bacon node broadcasts a beacon message throughout the network containing its location information with a hop count initialized to zero. The sensor nodes having received the information will record the minimal hop count to every beacon node and forward it to the neighbor node, ignoring the larger hop count at the same time. Through this mechanism, all nodes will receive the minimum hop value distance from each beacon nodes.

In the second stage, the beacons calculate average hop-distance according to the distance and hop-count information between it and other beacons. The average hop-size can be computed by beacon *i* as follow:

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

where (x_i,y_i), (x_j,y_j) are coordinates of beacon *i* and beacon *j*, h_{ij} is the hops between beacon *i* and beacon *j*. Once the average hop-size is calculated, each beacon node broadcasts its hop-size to network using controlled flooding. After receiving hop-size, all nodes can derive the physical distance to the beacon by using Eq.(2).

$$d_{ij} = HopSize_j \times hop_{ij} \tag{2}$$

where h_{ij} is the minimal hops between beacon *i* and unknown node *j*. Based on this method, each beacon node can convert the distance to physical distance.

In the third stage, each unknown node computes its location coordinate. Let (x, y) be the unknown node *P* location and (x_i, y_i) the known location of the *i*'th beacon node receiver. Let d_i be the *i*'th beacon node distance to unknown nodes *P*, then we have

$$d_i = \sqrt{(x - x_i)^2 + (y - y_i)^2} \tag{3}$$

If the node *P* gets its distance to three or more beacon nodes, the position of node *P* can be computed by using the following equation.

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

where,

$$A = 2 \times \begin{vmatrix} x_1 - x_n & y_1 - y_n \\ x_2 - x_n & y_2 - y_n \\ \vdots & \vdots \\ x_{n-1} - x_n & y_{n-1} - y_n \end{vmatrix} \tag{5}$$

$$b = \begin{vmatrix} x_1{}^2 + y_1{}^2 - x_n \ - y_n{}^2 - d_1^2 + d_n^2 \\ x_2{}^2 + y_2{}^2 - x_n \ - y_n{}^2 - d_2^2 + d_n^2 \\ \vdots \\ x_{n-1}{}^2 + y_{n-1}{}^2 - x_n{}^2 - y_n{}^2 - d_{n-1}^2 + d_n^2 \end{vmatrix} \tag{6}$$

$$X = \begin{vmatrix} x \\ y \end{vmatrix} \tag{7}$$

Now the least square solution is estimate for P that minimizes $\| AX - b \|^2$, then the position of P can be computed by the following formula:

$$X = (A^T A)^{-1} A^T b \tag{8}$$

2.2. Existing Improved DV-Hop Algorithm

DV-Hop algorithm is a typical range-free localization algorithm, whose basic idea relies on transforming the distance to all beacon nodes from hops the meters by using the computed average size of a hope. The advantages of the DV-Hop algorithm include simplicity, feasibility, cost-effectiveness and high coverage. It works well in isotropic networks. Major drawback of DV-Hop algorithms is its poor positioning accuracy.

To solve these problems, many researchers have proposed many schemes to improve location accuracy of DV-Hop algorithm [14-18]. In [14], the authors proposed a new localization algorithm and improve the DV-Hop algorithm by using a differential error correction scheme that is designed to reduce the location error accumulated over multiple hops. This scheme needs no additional hardware support and can be implemented in a distributed way. The proposed method can improve location accuracy without increasing communication traffic and computing complexity. In [15], Lin *et al.*, introduced an improved algorithm which revises the average distance of each hop in networks and the area range of estimated coordinate of unknown nodes. In [16], Boukerche *et al.*, proposed a novel localization-based protocol and show how Voronoi diagrams can be used efficiently to scale a DV-Hop algorithm while maintaining and reducing further DV-Hop's localization error. In [17], Zhang *et al.*, used correction value as the estimated distance between anchor nodes and unknown nodes and Total Least Squares(TLS) to enhance the localization accuracy. In [18], Gao *et al.*, formulated the hop-distance relationship for quasi-UDG model in WSNs where sensor nodes are randomly and independently deployed in a circular region based on a Poisson point process. They derived an approximated recursive expression for the probability of the hop count with a given geographic distance. The border effect and dependence problem are also taken into consideration. In [19], Kumar *et al.*, proposed an Advanced DV-Hop localization algorithm that reduces the localization error without requiring additional hardware and computational costs. The proposed algorithm uses the hop-size of the anchor, from which unknown node measures the distance. In [20], Yu *et al.*, presented an improved DV-Hop algorithm which uses the weighted average hop distances of anchor nodes within M hops to calculate the average hop distance of unknown nodes.

3. The Improved DV-Hop Algorithm

The DV-Hop localization assumes that if any two sensor nodes are in the radio range of each other, there is one hop in these two sensor nodes. And in these algorithms, this size of hop between different sensornodes is assumed equal, but in practical applications, this is not always possible. Actually, the real size of one hop between sensor nodes may be varied from zero to the range of communication radius of sensor nodes. As shown in Figure 1, the sensor node S_2 and S_3 are all in the radio range of sensor node S_1. Sensor node S_2 and S_3 are all have one hop from sensor node S_1, but there are great difference between the distance of sensor node S_1 and S_2, and that of sensor S_1 and S_3.

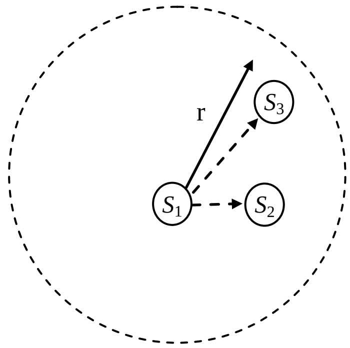

Figure 1. A Sample of Hop Analysis

In DV-Hop once a beacon node gets distances to other beacon node, it estimates an average size for one hop, which then floods this value to the entire network. And the unknown sensor node use the average of all hop size sent all beacon nodes as the hop size to compute its distance to beacon nodes. In the example in Figure 1, node S are unknown nodes and node B_1, node B_2 and node B_3 are beacon nodes. The hop count of node S to the three beach nodes are all 4. Suppose the hop size computed by the unknown node is L, and then the distance of node S_1 and S_2 to beacon node B are all $4L$. Obviously, the real distance of node S_1 and S_2 to beacon node B are not equal.

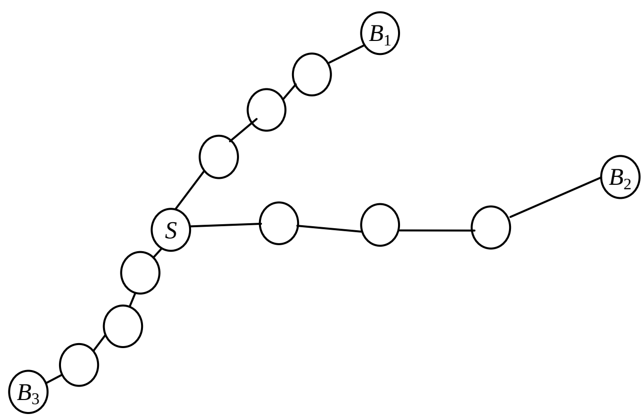

Figure 2. An Error Instance of the DV-Hop Algorithm

As DV-Hop localization algorithm performs by transforming the distance to all beacons form hop to units of length measurement using the average size of a hop, DV-Hop only works well for isotropic networks. As in isotropic WSNs, the properties of the network are the same in all directions, then the hop size can reasonably estimate the distances between hops. But in practical situation, most of WSNs are not isotropic. To solve this problem, we add correction to the hop count according the signal strength of received sensor nodes. Suppose sensor node j is in the radio range of sensor node i and sensor node i sends data to sensor node j, there will be a following hop correction:

$$c_{ij} = -\frac{\alpha I_r}{I_s} \tag{9}$$

Wherein r denotes communication radius of sensor node, and I_s denotes the transmitted radio intensity of sensor node i, and I_r denotes the received radio intensity of sensor node j and α denotes the parameter that affects the estimate distance between sensor nodes. Then the count of hop between sensor node i and sensor j will be $1+c_{ij}$.

Aiming at the defect of DV-Hop algorithm, an improved algorithm is presented here. We focus mainly on the first stage and the last two stages are the same as DV-Hop algorithm.

In the first stage, each beacon node broadcasts a message to be flooded throughout the network that contains its location information with hop-count value initialized to zero. On receiving the beacon packet, each sensor node maintains the position of the beacon (x_i, y_i) and the minimum hop-count hop_i to the particular beacon node i. If a received message contains less hop-count value to a particular beacon node, the corresponding hop-count hop_i will be replaced with the information in this message. Suppose the intensity of the receiving message is I_r, the sensor node compute the correction as Equation(9). And then this message is flooded outward with hop-count values incremented by $1+c_{ij}$. On the contrary, if the received message contains a higher hop-count value to a particular beacon node, this message will be ignored. Such updates and further broadcast will continue until all the shortest paths are found. Through this mechanism, all nodes in the network get the minimal hop-count to every beacon.

4. Simulation Study and Performance Analysis

In this section, we provide simulation results and analysis of the result for localization error. In order to verify of the proposed algorithm, we compare the localization error of our localization algorithm with that of DV-Hop algorithm.

For our simulation experiments, the network region is assumed to be a two dimensional area of $100m \times 100m$. The sensor nodes are distributed randomly in this region.

In this simulation, the localization error is defined as the average error function illustrated as follows equalization.

$$e_i = \frac{\sum_{i=M+1}^{N} \sqrt{(x_i - \overline{x_i})^2 + (y_i - \overline{y_i})^2}}{r \times (N - M)} \tag{10}$$

Where N is the number of sensor nodes, M is the number of beacon nodes, $(\overline{x_i}, \overline{y_i})$ is the actual coordinate of the unknown node i is, (x_i, y_i) is the evaluated coordinate, and r is the communication range of sensor nodes. The localization error reflects the accuracy of localization algorithm. The less the localization error is, the more accurate the localization performance.

4.1. The Impact of the Network Scale

Scalability is evaluated by varying the network size from 150 to 250. The ratio of beacon nodes is fixed in 0.1. Figure 3 shows the variation of average location error with respect to the number sensor nodes which is changed from 150 to 250. Figure 3 shows the proposed algorithm has an average localization error of about 39.0% when there are 210 sensor nodes whereas the DV-Hop has an average localization error of about 44.6%.

And the average error of the proposed algorithm is reduced about 16.9% compared to the DV-Hop algorithm.

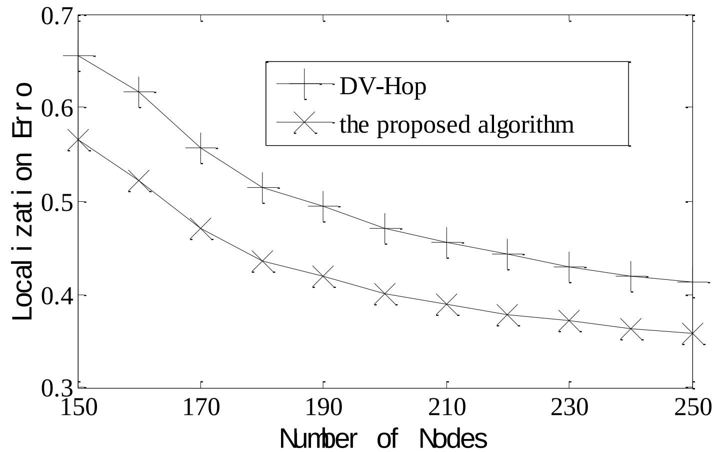

Figure 3. Localization Errors vs. Number of Nodes. Given there are 10 % Beacon Nodes

4.2. The Impact of Beacon Scale

Figure 4 shows the variation of the average location error with respect to the ratio of beacon nodes which is changed from 0.05 to 0.4. As shown in Figure 4, with the beacon nodes increasing, the average location errors of two algorithms present a downward and the present algorithm has a better performance that that of DV-Hop algorithm. For example, as in Figure 3, the proposed algorithm has an average localization error of about 38.4.0% when the beacon nodes ratio is 15% whereas the DV-Hop has an average localization error of about 46.5%.

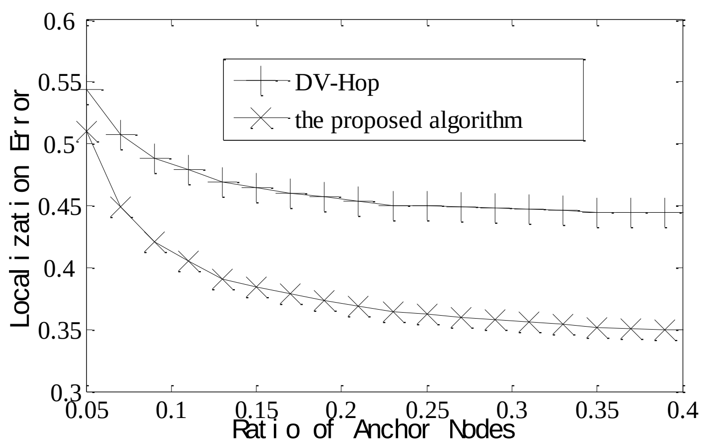

Figure 4. Localization Error vs. Ratio of Beacon Nodes .Given there are 200 Sensor Nodes

5. Conclusions

In this paper, we present an enhanced DV-Hop algorithm that reduced the localization error without requiring additional hardware cost. The proposed algorithm adds a correction to the hop count between the beacon nodes and the unknown nodes by using the RSSI of the received packets. The simulation studies are carried out to compare the performance the enhanced DV-Hop algorithm with the traditional DV-Hop algorithm. The effects of beacon ratio and network density on the performance on the enhanced DV-Hop are investigated. The simulation results indicate that the enhanced DV-Hop algorithm outperform the DV-Hop algorithm in all simulation cases. In the future, we will also like to extend this idea to other range-free localization algorithms.

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