Performance and Accuracy Analysis of Range-free Localization Algorithms in Wireless Sensor Network

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Abstract: Wireless sensor networks (WSN) are widely used in many environments to perform various monitoring tasks. In many such tasks, node location exists as permanent system parameter and to determine the exact position or location of sensor nodes in WSN is a big challenge to achieve. To achieve this challenge, various algorithms have been implemented to provide better accuracy even if anchor node density is less. The first aim of the survey is to explore various proposed techniques second is to compare their performance with their traditional techniques based on the anchor density and third is project which all improvements leads to the low localization error.

Keywords: Anchor Node Density, Centroid, DV-Hop, Localization, Range-Free, Weighted.

I. INTRODUCTION

Wireless sensor networks (WSN) consists of sensor nodes which senses the environment, perform computations, route data and communicate with each other. Nodes in WSN play a vital role in various monitoring task such as recovery, disaster support, research, target tracking etc. The challenge in such tasks are to locate the exact location coordinates of each sensor node [1] E.g., if there is a fire in the forest and if the sensor passes a measurement threshold, trigger raises an alarm signal, the alarm rings and call is made to the fire brigade, the exact locations or positions needs to be determined so that fire brigade can reach the target location at the right time and right location. Position can be determined by following ways.

First: Positions of the nodes can be determined if these nodes deployed are GPS equipped, but it has some limitations such as the power consumption and cost is high [1][2].GPS also requires a line-of-sight with a sufficient number of satellites, and can also fail in the presence of obstructions like indoors and underground, tall buildings, highways etc. The nodes whose location is known are called Anchor nodes (AN) which are undoubtedly but well-known location service used today [3]. Other way is to deploy or scatter the nodes randomly [4]. E.g., it can be deployed by dropping the nodes from the plane covering the whole area. Here the cost is relatively low even if the nodes are damaged or lost. But here the position coordinates of the nodes are unknown. The nodes whose location is not known are called Unknown nodes (UN). Task of the Anchor nodes is to help other unknown nodes to locate its position. The location coordinated of unknown nodes can be determined by two different methods; these methods are range-based and range-free [5].

Range-based method [6] requires distance or angle information to compute the coordinates of unknown nodes and provides high accuracy but it requires extra hardware to compute node coordinates which increases the number of computations. Range-free method [7] determines the coordinates of unknown node by utilizing the coordinate information of known nodes (GPS equipped nodes) and does not provide high accuracy but it consumes less energy and less cost as it does not require extra hardware.

Knowing relative locations are sufficient for certain applications. So here more attention is given to different algorithms that are based on range-free. In this survey, the goal is to explore the various proposed algorithms and latest introduced improvement in those algorithms and comparison is done between the proposed and traditional algorithm. Centroid and DV-Hop algorithms are given main attention in this paper. Section II classifies Localization. Section III compares the proposed Centroid algorithms and proposed DV-Hop Algorithms.

II. LOCALIZATION CLASSIFICATION

As mentioned above there are two methods to localize the unknown node. These methods are:

A. Range-based

B. Range-free

A. Range-based method

This method [5] includes different algorithm which requires hardware due to which cost increases. These algorithms localize the nodes using distance or angle information. These algorithms are AOA (Angle of Arrival), TDOA (Time Distance of Arrival), TOA (Time of Arrival) and RSSI (Received Signal Strength Indicator). These are explained as follows:

a. *Angle of Arrival (AOA):* The angle of signals is measured when signal arrives to the neighboring node or to a certain axis. On the basis of this angle information, the nodes can be localized. It includes difficulty in deployment purely based on angle is discussed in **[7][8]**

b. *Time Distance of Arrival (TDOA):* TDOA measure the signals time difference of arrival. Line of sight condition is required which is difficult to meet, but it provides extraordinary accuracy [5].

c. *Time of Arrival (TOA):* TOA captures the signal's time of flight and obtains the distance through multiplying the time of flight by the speed of signal **[5][7]**

d. *Received Signal Strength Indicator (RSSI):* RSSI is a cheap solution with respect to extra device because sensor nodes have radios (mostly each node is equipped with radios). But is not good solution because of large no. of anchor nodes are needed which increases the cost [6][3].

B. Range –Free method

This method [5][8] includes different algorithm to localize the co-ordinates of known nodes which does not require any hardware cost. Some of the methods are Amorphous, Approximation Point in Triangle (APIT), Centroid and DV-Hop.

a. *Amorphous Algorithm:* The Amorphous localization algorithm [10] [11] is similar to DV-hop. Unlike DV-Hop, calculates Hop Size offline.

b. *Approximation point in Triangle (APIT):* APIT [9] algorithm use the concept of triangle i.e. formed by three nodes called anchor nodes, determines whether unknown node deployed is inside a triangle or not. APIT is better than simple Centroid method but it is not able to judge in many cases whether unknown node deployed is inside or outside the triangle. If anchor density is high, it provides higher localization accuracy.

c. *Centroid Algorithm:* The Algorithm [12] determines the coordinates of the unknown node by calculating the Centroid of the polygon of anchor nodes. This algorithm is simple and easy to perform.

III. COMPARISON ANALYSIS

Different proposed algorithms of Centroid and DV-Hop algorithms have been discussed and comparison analysis has been done below.

A. Various Proposed Centroid Algorithm:

a. Traditional Centroid Algorithm:

Traditional Centroid algorithm was proposed by Bulusu et.al heidemann [13]. Centroid algorithm finds the location which fully depends upon the network connectivity. This algorithm needs minimum number of computations. In this Algorithm, anchor nodes periodically publicize the messages to all its neighboring nodes and that message has the details of anchor nodes i.e. ID and coordinates$(ID, Loc\ info(X_i, Y_i))$. If the unknown node receives the message from the anchor nodes which transcend a preset threshold value, the co-ordinate can be computed for an unknown node as the Centroid of the polygon is composed of the anchor nodes.

Assume the number of anchor nodes that includes its locations n, co-ordinates are (X_i, Y_i). Where $(i = 1, 2, 3, \dots, n)$. (X_{est}, Y_{est}) is the Unknown node estimated co-ordinates that can be computed using this formula (1) given below:

$$(X_{est}, Y_{est}) = \frac{(x_1+x_2+\cdots+x_n)}{n}, \frac{(y_1+y_2+\cdots+y_n)}{n} \quad (1)$$

The generalized formula is (2):

$$X_{est} = \frac{\sum_{i=1}^{n} X_i}{n}, Y_{est} = \frac{\sum_{i=1}^{n} Y_i}{n} \quad (2)$$

Error can be calculated using the following formula (3)

$$Error = \sqrt{(X_{est} - X)^2 + (Y_{est} - Y)^2} \quad (3)$$

Centroid algorithm is very simple and easy to implement as it requires less computation and the computation depends on the connectivity of the network. But it does not reflect the distance between the anchor nodes and

unknown nodes and it does not provide accurate results [13]. It requires high anchor node density to accurately localize unknown node.

b. Weighted Centroid Localization Algorithm:

Yu HU, Weizhao YAO proposed a new concept weighted to overcome the drawback of the traditional Centroid algorithm. Drawback is if i is anchor node and j is unknown node and i and j are close to each other, in other words, the distance between i and j is less as compared to other surrounding nodes then the influence between them i to j will be higher. But it requires the higher anchor density to compute the location with higher accuracy [14]. So the Weighted Centroid algorithm was proposed and the computing equations are shown in following formula (4)

$$X_{est} = \frac{\sum_{j=1}^{n} W_j X_j}{\sum_{j=1}^{n} W_j}, Y_{est} = \frac{\sum_{j=1}^{n} W_j Y_j}{\sum_{j=1}^{n} W_j} \quad (4)$$

Where W_j denotes weighted factor and it denotes the function which shows the distance between the anchor node and unknown node, n is number of anchor nodes.

c. Weighted Centroid algorithm based on DV-Hop:

Bingjiao Zhang, Minning Ji and Lianhai Shan [15] introduced a new method based on DV-Hop which was proposed to overcome the disadvantage of Weighted Centroid algorithm as it requires lower anchor density to compute the unknown location with high accuracy. DV-Hop requires minimum Hop count information. So the weighted values are expressed as follows in equation (5):

$$W_i = \frac{1}{Hop_i} \quad (5)$$

The weighted value is inversely propositional to the number of Hops.

d. Improved Weighted Centroid Algorithm based on DV-Hop:

In this algorithm based on DV-Hop, if node density is high between two nodes then the distance between nodes will be less but number of Hops will be high, this leads to increase in estimation error.

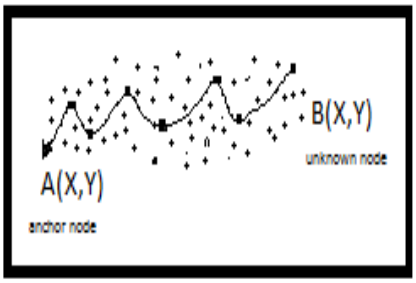

Figure 1: Distance and Number of Hops between AN and UN

Error is high even the distance between the nodes is less due to high anchor node density (greater no. of hops).

So DV-Hop cannot completely improve the accuracy of the Centroid algorithm. Some improvements were introduced in this algorithm by [16]. Unknown nodes maintain the record and arrange them from small to large and keep only those anchor nodes which have minimum number of Hops to that node. Unknown node maintains the average Hop distance to only above mentioned anchor nodes.

$$n = \frac{Hop\ Size_j}{r} \quad (6)$$

$Hop\ Size_j$ is the size of the average hop of the unknown node j, communication radius r is equal for all nodes, n is the number of anchor nodes [16].

So the derived formula is (7):

$$W_i = \left(\frac{1}{Hop_i}\right)^{\frac{1}{n}} \quad (7)$$

B. Various Proposed DV-Hop Algorithms

a. *Traditional DV-Hop Algorithm:*

American Drags Niculescu [17] proposed the DV-Hop (Distance Vector-Hop) Range-Free localization algorithm.

The algorithms can be implemented through following steps [18].

First step states that all anchor node broadcasts an anchor message($Loc\ info(X_i, Y_i), Hop\ Count = 1$). Hop count with minimum value is maintained by all receiving nodes and the value is incremented by 1 and forwarded to all other neighboring nodes. *Second*, average hop distance for every hop is estimated, which is broadcasted to the whole network. After receiving hop distance, anchors nodes multiplies the hop distance by the hop-count value. *Third*, once a node can calculate the estimated distance, it uses maximum likelihood estimation method.

Coordinates of the unknown node can be obtained using the standard minimum mean variance estimation method [18]

b. Improved DV-Hop localization Method:

Mostly in the virtual network distance errors are introduced due to the path between the unknown node and the anchor node is not a straight line. Improved DV-Hop method proposed in [19] by Wenqi Yu and Hao Li, in which corrections were done in average distance to improve its accuracy.

Now the average distance between the unknown nodes and the anchor nodes is represented by the formula (8):

$$d_{ij} = h_{ij} \times d + C_{ij} = h_{ij} \times d + \frac{h_{ij} \times (r-d)}{r} \quad (8)$$

This algorithm improves accuracy by reducing anchor node density. This decreases estimation error.

c. The Improved DV-Hop Localization Algorithm based on Centroid Algorithm:

If the distribution of node is uniform and anchor node density is high the error of average hop distance is small. This proposed algorithm [20] shows that which has less error with less no. of anchor nodes, improvements have been made i.e. if the anchor node's integer is K or higher than value 3 ($K \geq 3$), then the unknown nodes accepts the information of every $Hops_i$. However, the unknown node removes $MIN(Hops_a, Hops_b, Hops_c, Hops_d)$ e.g. $Hops_c$ and $MAX(Hops_a, Hops_b, Hops_c, Hops_d)$ e.g. $Hops_d$ with their corresponding h_i weights of the hop. Calculate every hop count value using the formula (9):

$$Hops = \frac{Hops_a \times h_a + Hops_b \times h_b}{h_a + h_b} \quad (9)$$

This Hops value is broadcasted to the whole network. The coordinates of the unknown nodes are calculated by using the Centroid of the estimated region.

IV. COMPARISON BETWEEN PROPOSED ALGORITHMS

TABLE 1 SHOWS THE COMPARISON BETWEEN DIFFERENT PROPOSED CENTROID LOCALIZATION ALGORITHMS

FACTORS	**LOCALIZATIONALGORITHM**			
	CENTROID LOCALIZATION ALGORITHM	**WEIGHTED CENTROID LOCALIZATION ALGORITHM**	**WEIGHTED CENTROID ALGORITHM BASED ON DV-HOP**	**IMPROVED WEIGHTED CENTROID ALGORITHM BASED ON DV-HOP**
FORMULA	$X_{est} = \frac{\sum_{i=1}^{n} X_i}{n}$, $Y_{est} = \frac{\sum_{i=1}^{n} Y_i}{n}$	$X_{est} = \frac{\sum_{j=1}^{n} W_j X_j}{\sum_{j=1}^{n} W_j}$, $Y_{est} = \frac{\sum_{j=1}^{n} W_j Y_j}{\sum_{j=1}^{n} W_j}$	$W_i = \frac{1}{Hop_i}$	$W_i = (\frac{1}{Hop_i})^{\frac{1}{n}}$
COMPLEX/ SIMPLE	Simple and Easy to Implement	Simple	Complex	Highly Complex
ANCHOR NODE DENSITY	High	High	Low	Low
FACTOR	Based only on connectivity	Based on distance	Based on distance and require hop count information	Based on distance and average hop distance
ERROR	High	High	High because of large no. of hops	Low
ACCURACY	High if AN density is high	High	High if less no of hops between AN and UN	V. High

TABLE 2 SHOWS THE COMPARISON BETWEEN DIFFERENT PROPOSED DV-HOP LOCALIZATION ALGORITHMS

FACTORS	LOCALIZATION ALGORITHMS		
	DV-HOP LOCALIZATION METHOD	IMPROVED DV-HOP LOCALIZATION METHOD	THE IMPROVED DV-HOP LOCALIZATION ALGORITHM BASED ON CENTROID ALGORITHM
COMPLEXITY	High	High	Low
DISTRIBUTION OF NODES	Straight line between AN and UN	Uniform	Non Uniform
ANCHOR NODE DENSITY	High	High	Moderate
ACCURACY	V. Low	Low if AN density is high	High

V. CONCLUSION

This paper introduces two techniques of localization in WSN; they are range-based and range-free algorithm. The two most efficient techniques of range-free localization are Centroid and DV-Hop that have been discussed in this paper. This paper also summarizes the comparison analysis of various proposed Centroid algorithms and various proposed DV-Hop algorithms based on different parameters. These comparison project that the latest proposed algorithm provides better accuracy even if anchor node density is less.

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