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A New Technique for Localization Using the Nearest Anchor-Centroid Pair Based on LQI Sphere in WSN

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Abstract

It is important to find the random estimation points in wireless sensor network. A link quality indicator (LQI) is part of a network management service that is suitable for a ZigBee network and can be used for localization. The current quality of the received signal is referred as LQI. It is a technique to demodulate the received signal by accumulating the magnitude of the error between ideal constellations and the received signal. This proposed model accepts any number of random estimation point in the network and calculated its nearest anchor centroid node pair. Coordinates of the LQI sphere are calculated from the pair and are added iteratively to the initially estimated point. With the help of the LQI and weighted centroid localization, the proposed system finds the position of target node more accurately than the existing system by solving the problems related to higher error in terms of the distance and the deployment of nodes.

Index Terms: Link quality indicator (LQI), Localization, LQI sphere, Wireless sensor network (WSN), ZigBee

I. INTRODUCTION

The improvement of wireless communication technologies and electronic systems is greatly accepted by Internet of Things (IoT) system due to easy implementation and rapid evolution of wireless sensor networks (WSNs). It consists of a number of sensors with tiny processors, low power supplies, and transceivers with memory devices. Each node follows the preprogrammed algorithms and the data transferring sink node which is responsible for data transmission. The feasibility of WSN's deployment in open environments and low-cost makes this technology more promising for different applications such as surveillance, home automation, human interfacing and livestock farming.

The amount of sensor deployment is increasing sharply due to its cost effective solution that makes issues of sensor localization which are more vital. Global positioning systems (GPS) are the most popular and widely used technology in recent days, but they require a high cost for implementation and a huge number of nodes are needed to be in the line of sight in order to communicate [1]. Furthermore, it does not work indoors such as in subways, under water, tunnels, etc.

Distance estimation technique is one of the most promising methods of localization in WSN networks that can be divided into range-based localization and range-free localization. Range-based localization uses estimated distance between two nodes by using physical properties communicated signals such as the Received signal strength indicator (RSSI) [2, 3], the LQI [4-6], time of arrival (ToA) [7], time difference of arrival (TDoA) [8], and angle of arrival (AoA) [9]. RSSI based techniques provide better accuracy of localizations in indoor systems, that is why range-based methods are considered as an accurate location estimation technique, but they need additional external hardware for outdoor localization. Recent techniques seek cost effective techniques rather than accuracy in an outdoor system this is known as range-free

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localization in WSNs. Recently, researchers are interested in developing a number of techniques in localization that boost accuracy with lower localization error. DV distance [10, 11], probability grid [12], and Kcdlocation algorithm [13] are based on anchor distance, whereas the convex position estimation technique localizes without an anchor node [14]. Due to the development of centroid algorithms in 3D positioning algorithm, location accuracy has been improved that is, it uses co-ordinate-tetrahedron in the volume co-ordinate system [15, 16]. Ad-hoc sensor network uses DV distance technique to find anchor node which are dynamic by nature. Although this method is adapted rapidly it has high error [17-20]. To find the number of unknown sensors within a large network, approximate point in triangulation (APIT) method uses triangulated distribution of centroids [21]. One of the error reducing technique under heterogeneous network is to provide the flooding number of unknown sensors in DV-hop algorithm [22].

The problem with range-free localization system is accuracy. We need a method that accepts less flooding of unknown nodes and the anchor nodes that are dynamic in nature. In this paper, we propose a novel concept that accepts three input parameters (unknown nodes, anchor nodes and deployment volume in 3D) as variables and provides accurate positioning in comparison to some existing system and comparison is done in result section. Proposed model describes that estimation point is the function of the nearest anchor-centroid pair in terms of Euclidian distance. Although link quality indicator (LQI) systems require additional hardware, they can accurately locate the target nodes. With the help of the weight factor, we can find the first estimating point and addition of LQI with this estimating point results the distance. This distance is sufficient for making an LQI-sphere and transferring the first estimation point near the target nodes.

II. RELATED WORK

A common LQI based expression that calculated the distance d_{ij} from anchor node i to target node j can be defined as

$$d_{ij} = k_0 \times 10^{-k_1 \cdot Q_{ij}}, \quad (1)$$

$$Q_{ij} = \frac{LQI_{ij}}{LQI_{max}}. \quad (2$$

The values of k_0 and k_1 depends upon the types of LQI device used. For this paper the values are 210 and 3.96, respectively because it is standard value for many kinds of LQI device. The value of LQI_{max} is 255.

Other studies [23, 24] shows two other expressions in which Eq. (3) is a variant of Eq. (2) as:

$$d_{ij} = \sqrt[\eta]{\left(\frac{\alpha}{Q_{ij}}\right)}. \quad (3)$$

Let α = 1 for calculation simplicity, then,

$$d_{ij} = (Q_{ij})^{\frac{-1}{\eta}}. \quad (4)$$

The value of η is 2 for free space.

Improved weighted centroid (W) algorithm was proposed by Shang et al. [25]. Basic mathematical form of this algorithm is:

$$W = \left(\frac{1}{h}\right)^{\frac{r}{AHD}}. \quad (5)$$

Here, AHD is the average of all the hop distances computed by each node, r is the communicating radius of any node taken at that point and h is the minimum hop count. Hop count refers to the number of nodes that is within r.

III. MATHEMATICAL MODEL

To increase the system accuracy a self-correcting mechanism, 'anchor centroid pair based localization algorithm' is proposed. The network is equipped with three types of devices that are anchor node A_i (x, y, z), a centroid node C_k (x, y, z) and a corresponding target node T_j (x, y, z). Reference node, R_1 (x, y, z) is required to initiate the process. There could be any number of anchor nodes and target nodes in the system. We mainly focus on reducing the error in the system although the number of anchor nodes are not that much sufficient. Initially the scattered nodes in the network system called anchor nodes are used to calculated the centroid nodes simply by applying the triangular distribution as

$$C_k = \frac{1}{3}\Sigma_1^3 A_j, \; k = 1, 2, \ldots (i-2). \quad (6)$$

The number of centroid node is always 2 less than that of the anchor nodes. Hence the minimum number of anchor nodes for this system to operate is 3.

After the calculation of the centroid node the distance between all the anchor nodes and reference node is calculated simply by using the Euclidean formula as

$$D = \sqrt{(R_x - A_x)^2 + (R_y - A_x)^2 + (R_z - A_z)^2}. \quad (7)$$

And the distance between centroid node and the reference node is calculated in the same manner as

$$D = \sqrt{(R_x - C_x)^2 + (R_y - C_x)^2 + (R_z - C_z)^2}. \quad (8)$$

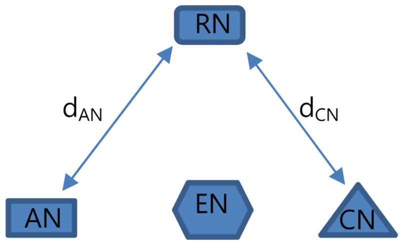

Fig. 1. Selection of the anchor-centroid pair.

Once all the distances are calculated, one anchor node and one centroid node are paired. Anchor node and centroid node which have shortest distance with reference node are paired first and so on.

The notations in Fig. 1 are as follow:

RN: reference node,
AN: anchor node,
EN: estimated node,
CN: centroid node,
d_{AN}: distance between RN and AN,
d_{CN}: distance between RN and CN.

Let W_A and W_C be the calculated weight factors of anchor node and centroid node, respectively from Eq. (5) then our first estimated node is located at

$$E_i = W_A \times A_i(x,y,z) + W_C \times C_k(x,y,z)\,. \tag{9}$$

From the equation above we can interpret that the estimation point is the function of anchor node and centroid node. If the distance between this estimation node and the target node is calculated, then the error is high. Mathematically, it can be represented as

$$f(E_i) = D_{min}(A_i, C_k)\,. \tag{10}$$

As LQI is a function of distance, we can measure the LQI value at the anchor node and the centroid node (Table 1). After we know the location of the estimated node we can carry our next process which would be acquiring the LQI values from each node of anchor-centroid pair. The main advantage of using LQI as the distance function is that it can locate maximum number of target nodes within minimum number of iteration so there is less power consumption.

Moreover, it is easy to modify the value of LQI distance if target nodes are not within the range, that is, if it possesses huge error. This LQI value is used by Eq. (2) to calculate quality index.

Let Q_A and Q_C denote the quality index value of anchor node and centroid node, respectively, then by using Eq. (4):

$$r = d_{corr} = (Q_A + Q_C)^{\frac{-1}{\eta}}\,. \tag{11}$$

Table 1. Distances of two nodes according to the LQI value

LQI	Q_{ij}	D (m)
70	0.0582	17.1854
100	0.1707	5.8787
120	0.4700	2.8700
135	0.5946	1.6817
140	0.7110	1.4064
145	0.5686	1.1760
150	1.0167	0.9836
160	1.4537	0.6879
200	6.0753	0.1646
220	12.4224	0.0805
240	25.3807	0.0394

From the estimation point, Eq. (9), we construct a sphere having radius 'd_{corr}'. Eight new estimating points are now located at the surface of the sphere and it can be done by

$$\vec{S} = \begin{pmatrix} r & r & r \\ r & r & -r \\ r & -r & r \\ r & -r & -r \\ -r & r & r \\ -r & r & -r \\ -r & -r & r \\ -r & -r & -r \end{pmatrix}. \tag{12}$$

Here, we assume that, if we take 3D matrix which is made by its positive and negative values then the coordinate for next estimation point lies in the surface of the LQI sphere whose radius would be $\beta \times d_{corr}$. Here β is the constant value and solely depends upon the value of d_{corr}. Initially, d_{corr} is multiplied by a unitary matrix S. This matrix contains all the possible positive and negative nodes. The estimating point again becomes a function of the distance between target node and the shifting of the first estimating node (Fig. 2). Distance between these points can be calculated as

$$f(E_i) = D_{min}(E_i + S_j, T_i)\,,\ j = 1, 2, \ldots 8\,. \tag{13}$$

T_i refers to the set of new coordinate located at the circumference of the LQI sphere and the direction is denoted by S_j. If j becomes the new lowest error coordinate of the LQI sphere, then the second estimated point will be

$$E_i'' = E_{i'}' + d_{corr} \times \vec{S}_j\,, \tag{14}$$

where $\vec{S}_j$ is the direction of the shifting coordinate. We again apply this unit matrix to the next iteration. During each itera-

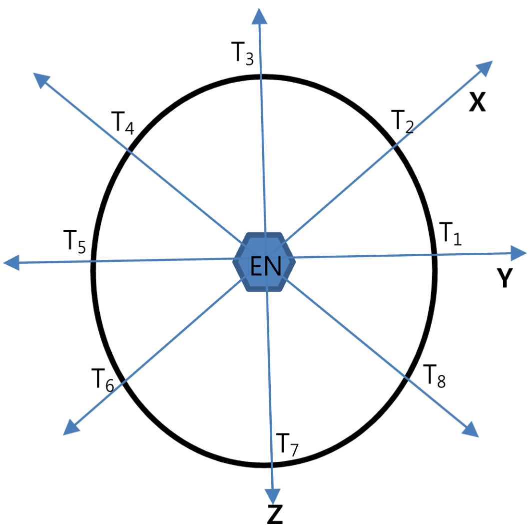

Fig. 2. Division of the LQI sphere by taking each axis's positive and negative coordinates.

tion the value of d_{corr} is varied as

$$r = d_{corr1} = \frac{d_{corr}}{2}. \qquad (15)$$

Now, if this process is continued n times, then our estimated point becomes as follow:

$$T_i = E'_{i'} + \Sigma_{i=1}^{n} \frac{(Q_{AN}+Q_{CN})^{-\alpha}}{2^{n-1}} \times \vec{S}_j . \qquad (16)$$

Here, Q_{AN} and Q_{CN} refers to the quality index of the newly found anchor node and centroid node, respectively.

IV. RESULTS

The system is called dynamic if all the inputs are variable. This proposed method treats the number of deploying anchor nodes, the number of deploying unknown nodes and the amount of deploying volume as an input variable. For simulation, each time we have to take two parameters as a constant and find the localization error distance from the third parameter and compare with the existing system. In order to get the result, the number of iteration is 4 times, that is, n = 4 and this value of n increases with the increase in parameters such as target nodes, anchor nodes and working space. Data fusion algorithm plays significant role in achieving reasonable performance [26].

Fig. 3. Shows the results of position of the anchor nodes, the estimation nodes, and the target nodes in 100 m × 100 m × 100 m 3D space. First we take the varied 3D working space with constant anchor nodes and estimated nodes to be 20 and 50, respectively. The result shows an error distance ratio around 0.02, which is far better than the existing novel distance estimation using MDS [27] in Fig. 4. Second, we take the estimated nodes to be 50 and each axis distance 100 m with variable anchor nodes. Simulation shows that our proposed system has a maximum of 40% improvement in error distance percentage over the existing USC Monte Carlo localization [28] in Fig. 5. Third, we take the anchor node and each axis distance to be 20 and 100 m, respectively, but the number of deployment of target nodes is variable. It gives around 1.3 m error distance which is far better than Modified APIT (R = 50 m) and DL (R = 50 m) [29] as shown in Fig. 6.

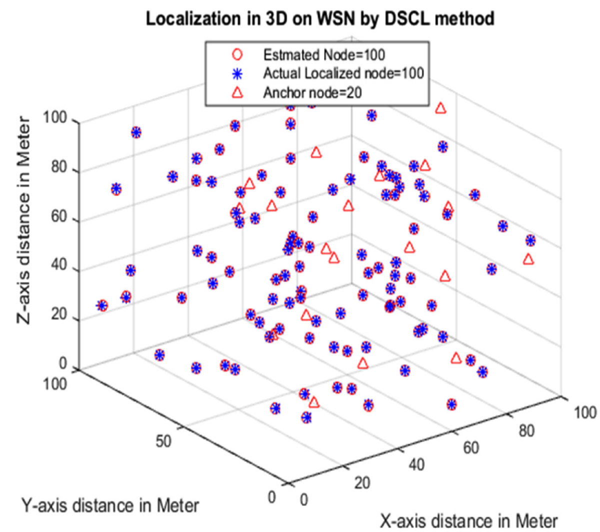

Fig. 3. Position of different kind of nodes.

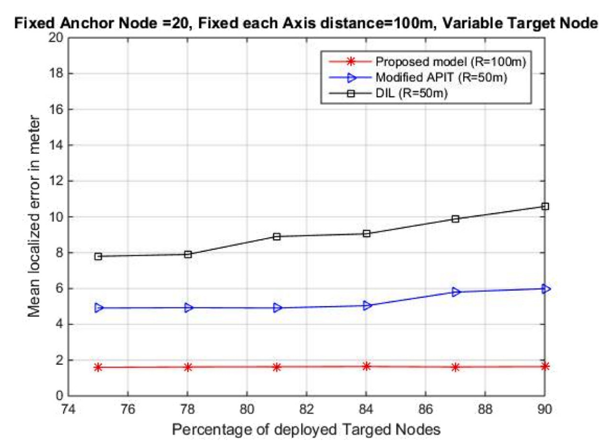

Fig. 4. Error distance ratio.

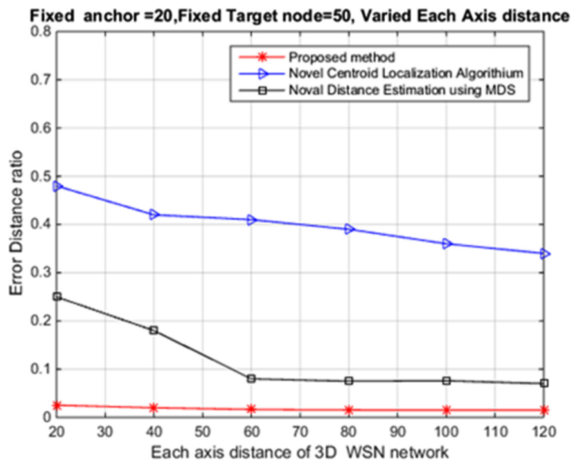

Fig. 5. Improvement in error distance over the existing system.

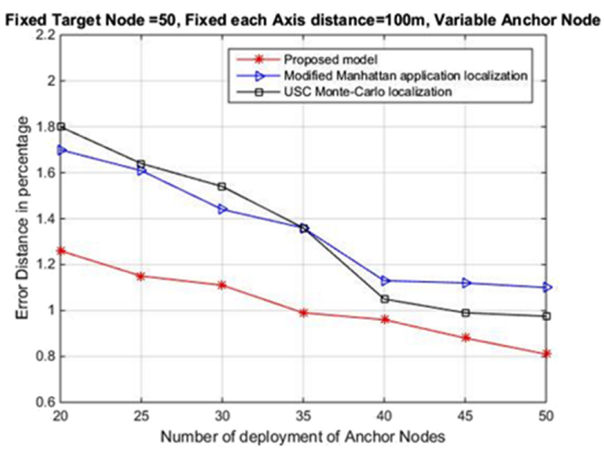

Fig. 6. Modified error in terms of distance.

V. CONCLUSION

In this paper, we introduce a LQI and anchor-centroid node pair. Our simulation results show better performance in different variable input conditions of the WSN than the existing system. The LQI sphere coordinates greatly enhance accuracy and the positioning of the WSN. The criteria were different, longer route (100 m in Fig. 4) for our algorithm to be more precise, but the results were better than other algorithms. Considering the applications in which we are expected to have more number of nodes, we believe that our algorithm has more practical merit. The proposed model provides efficient reduction in the percentage error distance while each anchor node, target node and the working volume can be varied individually. As a future work, we plan to investigate the possible effects of pressure, humidity and temperature in our algorithm.

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