DESIGN AND ANALYSIS OF A BORDER-DETERMINING RANGE FREE LOCALIZATION SCHEME BASED ON FUZZY LOGIC INFERENCE SYSTEM FOR WIRELESS SENSOR NETWORKS

Usman Hassan, Fahim Gohar Awan, Asima Kiran
Department of Electrical Engineering, UET, Lahore, Pakistan

ABSTRACT*—Range-free localization methods are suitable in many sensor networks where accuracy requirements are not very strict. In many of these methods, a sensor node estimates its coordinates as weighted average of coordinates of neighboring anchor nodes with known locations. However, in many situations, sensor nodes are deployed in a particular geometric layout, e.g. in C-shape around a lake. This paper proposes a simple yet effective algorithm to determine if a sensor node is very close to a known physical boundary. In that case, weighted average of either x or y coordinate is not required. It is demonstrated that the proposed method outperforms the simple centroid localization scheme in terms of complexity and localization error.*

Index Terms —Wireless Sensor Networks, Node Localization, Centroid Algorithm, Edge weight, Fuzzy logic system.

I. INTRODUCTION

Wide range of applications in the domain of wireless sensor networks (WSN) has gained research attention where localization of nodes is challenging and is difficult using conventional means [1, 2, 3]. The WSN applications largely depend on accurate localization of sensor nodes. Localization techniques are broadly categorized either as range-free or range-based. The range-free scheme does not require additional gadget for the sensor nodes. Not all the WSN applications require high localization accuracy and coarse localization accuracy would be sufficient. The costly range based localization techniques are being replaced with range-free localization techniques for these applications. The cost of WSN escalates if all nodes are location aware. This cost is reduced by deploying a few locations-aware anchor nodes and making geographical location of all other sensor nodes relevant to the known position of these anchor nodes.

This study proposes an effective, low-cost solution to the WSN localization scheme. The research work is performed in two steps. As a first step, three ranges-free localization schemes for wireless sensor networks proposed in [4] are analyzed. These are low cost solutions as compared to their localization counterpart techniques which are range based. These range-free schemes are Centroid based localization technique and fuzzy logic interference (FLI) schemes, namely Mamdani FLI approach and Adaptive-Network-Based Fuzzy Inference System (ANFIS) trained Sugeno weighted FLI approach [4, 5,6,7].

Secondly, based on the observations from the results of the first step, we have designed a scheme that enables a sensor node to determine if it is in proximity to top, left, bottom or right border of a rectangular layout. In that case, for estimation of one or both of its x and y coordinates, the sensor node is able to choose the corresponding coordinate(s) of one of its neighboring anchor nodes that is closest to it, instead of taking the weighted centroid of coordinates of all of its neighboring anchors. The other coordinate is determined by calculating a weighted average of the corresponding coordinates of neighboring anchors. This scheme is termed as "Usman's Border-Determining Localization Scheme". This scheme is simulated in Matlab for the layout of sensor and anchor nodes presented in [4]. The results show that this scheme brings thirty percent improvement in the accuracy of simple centroid localization.

In the next section of this paper, fuzzy inference system and weighted centroid localization are introduced. Further Mamdani localization and ANFIS trained Sugeno schemes from the implementation point of view are described. Then it describes a novel "Usman's Border-Determining Localization" Scheme. Section 3 presents test environment, simulation results and analysis of aforementioned schemes. Finally, section 4 concludes the results.

II. MODELING ANALYSIS

We first introduce the centroid and weighted centroid localization schemes and then discuss weight optimization brought by FLI schemes.

In centroid localization technique, the position of the centroid of anchor nodes connected to it is computed via sensor node through

$$(X_{est}, Y_{est}) = \left(\frac{X_1 + \cdots + X_N}{N}, \frac{Y_1 + \cdots + Y_N}{N}\right). \quad (1)$$

Where X_{est}, Y_{est} denote the estimate of the location of a sensor node, total number of its neighbors will be N, and (X_i, Y_i) will denote the position of any anchor node$(i = 1,2,3, \ldots, N)$.Simple centroid results based on equation (1) are very poor. For all connected anchor nodes with sensor node, an improvement is achieved by applying edge weights [8] to this centroid localization. This computation follows the following equation:

$$(X_{est}, Y_{est}) = \left(\frac{w_1 X_1 + \cdots + w_N X_N}{w_1 + w_2 + \cdots + w_N}, \frac{w_1 Y_1 + \cdots + w_N Y_N}{w_1 + w_2 + \cdots + w_N}\right). (2)$$

where w_i represents the i^{th} anchor node edge weight.

Using different FLI systems, we optimize the edge weights to improve the performance of the above scheme. The basic idea is to give those neighboring anchors more weights from which the received signal strength is high.

In the models that we have discussed, beacon signals from anchor nodes are assumed to be transmitted periodically. Further transmission range and pattern of each node is assumed to be spherical and similar. These signals carry respective position information. The sensor nodes are uniformly distributed in a square field. Each sensor node is also able to compute the received signal strength from these beacon signals originated from connected anchor nodes. This parameter helps in computing the edge weights.

Received signal strength information (RSSI) from each anchor node is scaled assuming a value in the range [0, $RSSI_{max}$=100]. Fuzzy logic input membership functions are defined over this interval [0, 100], as described below, to determine the degree to which RSSI of an anchor node is very low, low, medium, high or very high. These membership values are fed to If-Then rules. The output of the If-Then rules is the firing degree of each of the output weight membership functions. Weight membership functions have also five categories; (1) very low, (2) low, (3) medium, (4) high and (5) very high. To obtain the crisp value of the output weight for an anchor, we applied compression on weight membership functions according to their respective firing degrees, combined them and found the weight value that bisects the area under combined weight memberships into two equal halves. If-Then rules are very simple as defined in table 1.

Table 1.
If-Then rule of Weight Function

RSSI	Weight membership functions/ Category
Very Low	Very Low/ 1
Low	Low/ 2
Medium	Medium/ 3
High	High/ 4
Very High	Very High/ 5

For Mamdani FLI System the edge weights are calculated as follows.

- Transform each RSSI linearly to scaled RSSI [0-100]
- For each scaled RSSI, obtain 5 membership values from Figure 1 [4]
- Feed 5 RSSI values to If-Then rules mentioned in table 1
- If-Then rules yield 5 firing degrees for 5 weight membership functions defined in Figure 2 [4]
- Apply area-bisector method to obtain a crisp value of output weight

ANFIS on a prescribed data set can construct an FLI. The tuning of its membership function parameters is done jointly using a least squares technique or with a back propagation algorithm. Thus the fuzzy system learns from the input output data set being modeled. The Sugeno FLI (which itself has input RSSI membership functions same as Mamdani but its output membership function is linear) is trained using ANFIS [4]. The resultant edge weights are linear corresponding to RSSI as shown in Figure 3 [4].

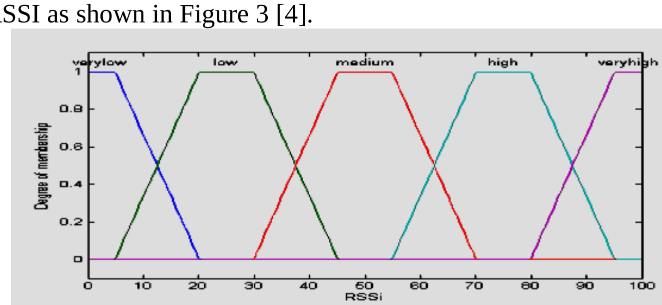

Fig 1.Mamdani fuzzy membership function of RSSI

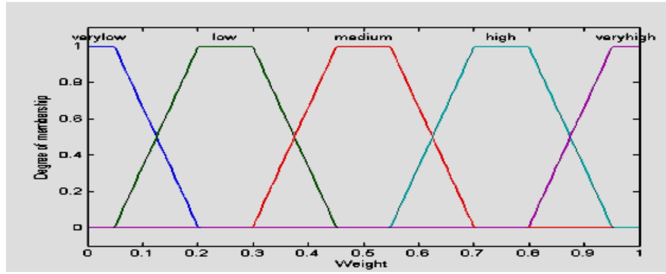

Fig 2.Mamdani fuzzy membership function of weight

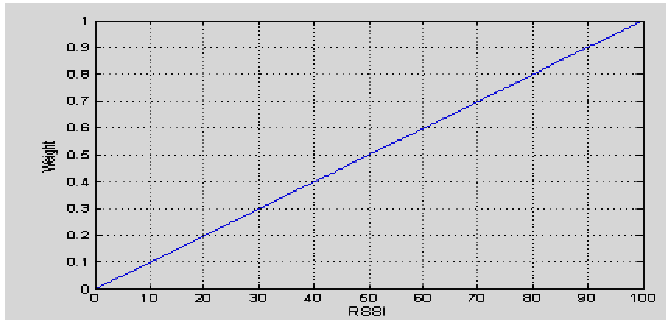

Fig 3. Relationship between RSSI and weight for ANFIS trained Sugeno

The algorithm for edge weight calculation works as follows.

- Transform each RSSI linearly to scaled RSSI [0-100]
- Transform each scaled RSSI directly into output weight value using Figure 3

The proposed Usman's Border-Determining Localization Scheme (UBLS) is described in three steps.

I) If a sensor node is located close enough to any boundary wall of the rectangle enclosing the deployed nodes, either x-distances or y-distances between all possible pairs of its neighboring anchors cannot exceed the radio range.

Consider the sensor node close to the left boundary of a rectangular or C-shaped field as shown in Figure 4. As it has no neighboring anchor nodes on its left, we have

$$|x_i - x_j| < radio\ range\ of\ sensor\ node\ for\ all\ i, j \in N$$
$$|y_i - y_j| > radio\ range\ of\ sensor\ node\ for\ some\ i, j \in N$$

Same is the case for a sensor node in proximity of the right boundary of a rectangular or C-shaped field. Similarly, for a sensor node close to top or bottom boundary of a rectangular or C-shaped field, we have

$$|x_i - x_j| > radio\ range\ of\ sensor\ node\ for\ all\ i, j \in N$$
$$|y_i - y_j| < radio\ range\ of\ sensor\ node\ for\ some\ i, j \in N$$

II) After a node is detected to be close to a boundary, it is disadvantageous to apply weighted centroid method to obtain estimate of one of its x and y coordinates. Simply choose the corresponding coordinate of the neighboring anchor node closest to the identified boundary. For example, in case of Figure 4, estimates are obtained as follows.

X_{est} = x-coordinate of the neighboring node closest to the left wall

Y_{est} =obtained by applying weighted centroid method

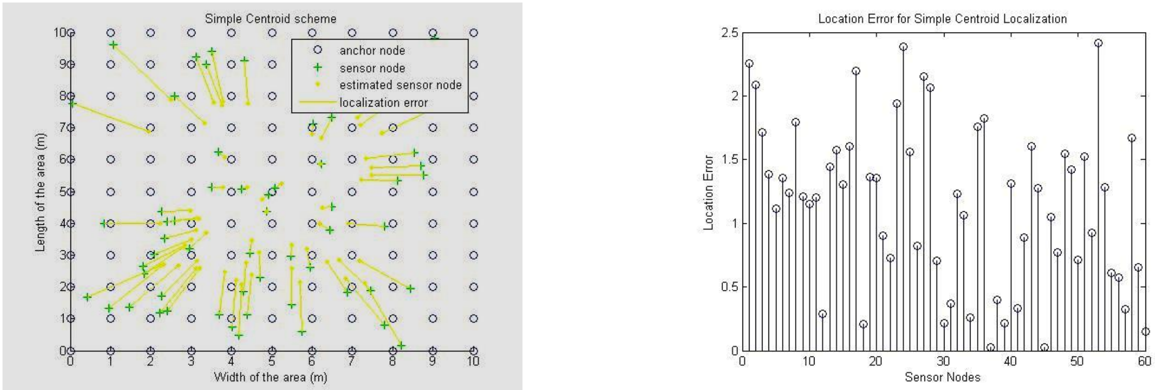

Fig 5. Simple Centroid Scheme Location error

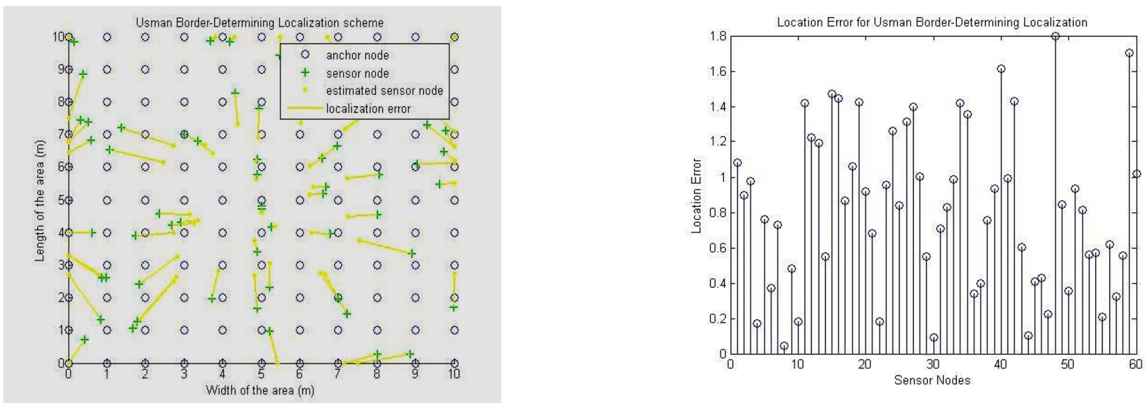

Fig 6. Border-Determining (UBLS) Scheme Location error

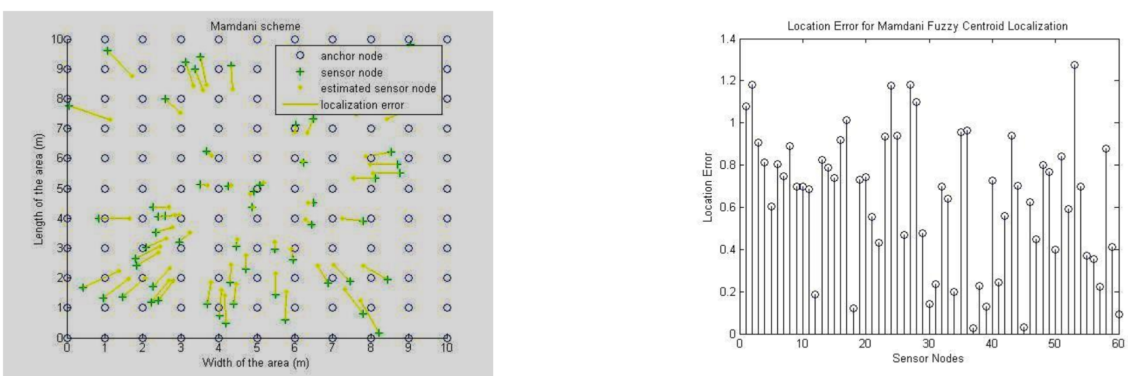

Fig 7. Mamdani FLI Scheme Location error

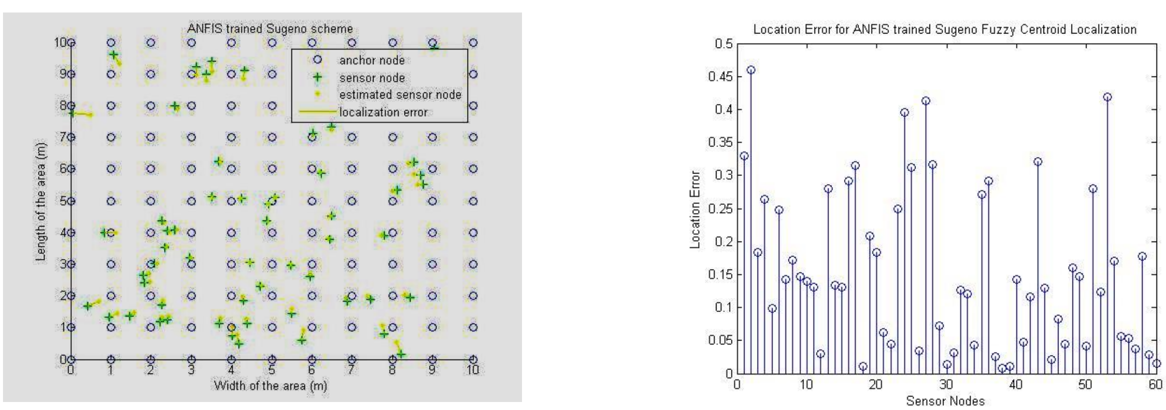

Fig 8. Sugeno ANFIS FLI Scheme Location error

III) To apply the scheme proposed in step II, we need to tell a node near the left border apart from a node near the right border in vertical boundary case; and we need to differentiate between a node near top border and a node near bottom border. This is done as follows in case of a vertical boundary. Arrange the x-coordinates of all neighboring anchors in ascending order, i.e. $\{x_1, x_2, \ldots, x_N\}$, such that $x_1 < x_2 < x_3 < \cdots < x_{N-2} < x_{N-1} < x_N$

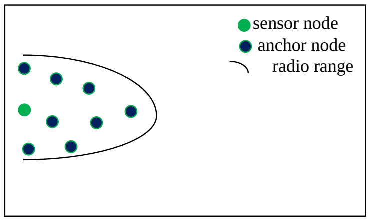

Fig 4.Sensor node near left border. The anchor nodes can be present on its right, top and bottom but not on its left.

If our node is near left border, then many small values x_1, x_2, x_3 will have very small difference in value. If our node is near the right border, then many large values $x_{N-2}, x_{N-1} and x_N$ will have very small difference in their values.

III. SIMULATION SETUP AND RESULTS

For testing the performance of the simple centroid scheme on all the scenarios described in section II, 60 sensor nodes each with uniform PDF in an area of $10 \times 10\ m^2$ were placed. 121 anchor nodes were deployed with both horizontal and vertical spacing equal to1 m. Radio range was varied from 3 m to 7 m and its effect on the accuracy of estimation was investigated.

To obtain RSSI, direct path free space radio model for range free localization [9], [10] was employed as

$$R_{ij} = 50 \times d_{ij}^2. \quad (3)$$

Where d_{ij} is the distance between i^{th}sensor node and j^{th}adjacent anchor node, andR_{ij} is RSSI value received at i^{th}sensor node transmitted by j^{th}adjacent anchor node.

Figures 5 to 8 show the simulation results while Table 2 shows how average location error varies with radio range in each scheme.

It is worth noting that in all schemes, location error increases for an increase in sensing range of the sensor node. The reason for this behavior is the high anchor density in the simulation setup. Large radio range includes far-away anchor nodes in estimation process, yielding errors. If anchor nodes are less dense, then the large radio range is likely to be beneficiary.

Table 2

Average Location Error versus Radio Range

Scheme	3m	5m	7m
Simple Centroid	0.48m	1.28m	2.23m
UBLS	0.33m	0.88m	1.73m
Mamdani FLI	0.19m	0.71m	1.49m
ANFIS trained Sugeno	0.08m	0.18m	0.28m

ANFIS-Sugeno scheme has a linear relationship between RSSI and weights where membership functions are not involved. So fuzzification and defuzzification are not performed in this scheme. This scheme outperforms the Mamdani scheme in which trapezoidal membership functions are involved both for input and output. But with line of sight Physical model, RSSI and weights are proportional and membership functions do not obtain a directly proportional relationship between RSSI values and weights. Hence, Mamdani scheme, though far better than simple centroid scheme, is less accurate than ANFIS trained Sugeno scheme.

The benefit of our proposed scheme is that by identifying the border node the anchor nodes are prevented from unnecessarily pulling the estimate towards the center of the field. From Figures 5, 6, and Table 2, it is observed that our proposed scheme outperforms the simple centroid scheme by approximately 30%.

IV. CONCLUSION

In this paper, we have studied range-free localization methods using Fuzzy Logic. Then we redesigned the layout of sensing the environment to enhance the performance of a particular localization scheme. It is concluded that the proposed scheme outperforms the simple centroid localization scheme by approximately 30%.

V. FUTURE WORK

This work can be extended by incorporating the scheme into Mamdani and ANFIS-trained Sugeno fuzzy localization schemes. And it is expected that proposed scheme will improve the accuracy of estimation by these schemes as well.

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