A New Fuzzy Based Localization Error Minimization Approach with Optimized Beacon Range

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ABSTRACT
One of the fundamental problems in wireless sensor networks (WSNs) is localization that forms the basis for many location aware applications. Localization in WSNs is to determine the physical position of sensor node based on the known positions of several nodes. In this paper, a range free, enhanced weighted centroid localization method using edge weights of adjacent nodes is proposed. In the proposed method, first the adjacent reference (anchor) nodes which are connected to the node to be localized are found, and then the edge weights based on received signal strength indicator information (RSSI) using Mamdani and Sugeno fuzzy inference systems are calculated. After localizing the sensor node by weighted centroid formula using both the Mamdani and Sugeno fuzzy system, a combined approach to localize the node is employed. Finally, the proposed method is simulated to demonstrate the performance by comparing them with the simple centroid, individual Mamdani and Sugeno fuzzy method. Location accuracy is further enhanced by calculating the optimized beacons transmission range to minimize the localization error.

General Terms
Algorithms, Measurement, Performance, Design, Reliability, Experimentation, Theory, Verification.

Keywords
Centroid localization, Edge weight, Fuzzy logic system, Range-free localization, Wireless Sensor Networks.

1. INTRODUCTION
Localization (location estimation) capability is essential in many WSN applications as the availability of location information may enable a myriad of applications such as target tracking, intrusion detection, wildlife habitat monitoring, real-time traffic monitoring, military, health and home application [3][5]. Wireless sensor networks consist of two types of nodes: anchor nodes and sensor nodes. Anchor nodes have sufficient energy and correct information about their position, while sensor nodes do not. Location information of unknown sensor node, is one of the essential problems for the location based services, and plays an important role for different application scenarios in WSNs [1] [11] [13]. Based on the researches, localization algorithms can be divided into two categories: range-based localization methods [7] [10] and range-free localization methods [4] [9] [12]. Range-based localization methods depend on either node-to-node distances or angles for estimating location which can be estimated using techniques such as time of arrival (TOA), time difference of arrival (TDOA) and angle of arrival (AOA). These range-based schemes typically have higher location accuracy than the range-free schemes but are hardware intensive [2]. In contrast, range-free localization schemes do not need distance or angle information from anchor nodes to sensor nodes for localization. Normally range free methods produce less accurate location results than the range based methods, but the design of hardware can be greatly simplified, making rang-free localization very economic and appealing for WSNs. In [9], a range-free, simple and in [15] an enhanced centroid localization algorithm is used to calculate a node’s position based on location of several connected anchor nodes.

In this paper, a range-free localization approach based on Received Signal Strength Information (RSSI) has been proposed. The edge weights, calculated from Mamdani and Sugeno fuzzy inference system, have been used to calculate the location coordinates of sensor node. The adjacent anchor nodes which are connected to the sensor node to be localized are found. First of all, the edge weight of each anchor node is calculated by using symmetrical trapezoidal membership function for “RSSI” and “Weight” using Mamdani fuzzy inference system. Then, the Sugeno fuzzy inference system is used instead of Mamdani to calculate the edge weights. In both the approaches, no optimization through Genetic Algorithms (GAs) or other methods is used. After calculating edge weights the weighted centroid method is employed to localize the sensor node. In the proposed approach, the average of location coordinates calculated from Mamdani and Sugeno approach is used to find out the location of sensor node.

The anchor beacon transmission range is having the great effect on sensor localization. Simulation system can be used to find out the optimal value of beacon range to further minimize the location error and improve the system efficiency.

Rest of the paper is organized as follows. In section 2, some background including the centroid localization, enhanced centroid localization and fuzzy logic system is introduced. In section 3, concept of localization using fuzzy logic is presented. In section 4, the simulation tool and environment setup is presented. In section 5, simulation results for performance evaluation are shown. Section 6 find the optimized anchor beacons range for minimum localization error, and finally section 7 draws the conclusions.

2. FUNDAMENTALS

2.1 Previous Localization Approaches

N. Bulusu and J. Heidemann [9] proposed a range-free, proximity-based, and coarse-grained localization algorithm that uses the broadcasted anchor node position (X_i, Y_i) by anchor beacons and each sensor node computes its position as a centroid of the positions of all the connected anchor nodes to itself by

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

where (X_{est}, Y_{est}) represents the estimated position of the sensor node and N is the number of connected anchor nodes to the sensor node. The scheme is quite simple and economic but shows large location error.

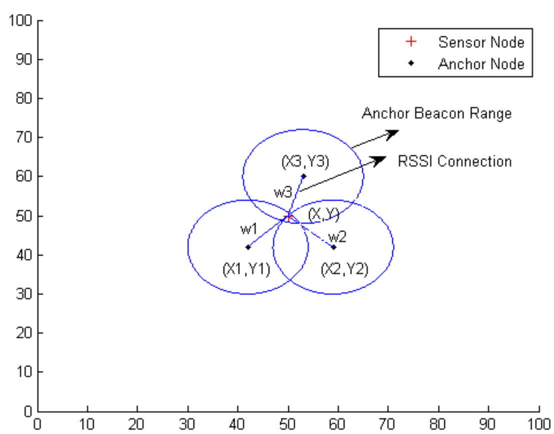

Figure 1. Weighted Centroid Localization

An improved version of [9] was proposed by Kim and Kwon [6]. In the improved version, location of sensor node is calculated by using edge weights of anchor nodes connected to sensor node, and each sensor node computes its position by

$$(X_{est}, Y_{est}) = \left(\frac{w_1 \bullet X_1 + ... + w_N \bullet X_N}{\sum_{i=1}^{N} w_i}, \frac{w_1 \bullet Y_1 + ... + w_N \bullet Y_N}{\sum_{i=1}^{N} w_i} \right) \quad (2)$$

where w_i is the edge weight of i^{th} anchor node connected to the sensor node. Performance of this approach highly depends on the design of edge weights.

Figure 1 shows the localization scenario for wireless sensor network. Sensor node is connected to more than one adjacent anchor nodes through beacon signal. Weights are calculated using the RSSI.

2.2 Fuzzy Logic System

A very simple approach for designing of edge weights for anchor nodes is fuzzy logic system [14] [15]. The fuzzy logic system (FLS) is an inference system which maps an input space to an output space, and the primary mechanism for doing this is a list of if-then statements called rules. A fuzzy logic system consists of a fuzzifier, some fuzzy IF–THEN rules, a fuzzy inference engine, and defuzzifier.

A fuzzy rule is written as the following statement:

Rule i: IF x_1 is A_1^i and x_2 is A_2^i and ……x_N is A_N^i THEN y is y^i

where i (i=1,2,…..l) denotes the i^{th} implication and l number of rules; x_j (j =1,2, ….,N) is input variables of the FLS; y_i is a singleton; A_j^i is the fuzzy membership functions, which represent the uncertainty in the reasoning. For the product inference, center-average and singleton fuzzifier, the output of the fuzzy system for an input X = (x_1, x_2…., x_N) can be expressed as [14],

$$y = \frac{\sum_{i=1}^{N} \alpha_i y_i}{\sum_{i=1}^{N} \alpha_i} \quad (3)$$

where α_i implies the overall truth value of the premise of the i^{th} implication, and are computed as

$$\alpha_i = \prod_{j=1}^{N} A_j^i (x_i) \quad (4)$$

3. LOCALIZATION USING FUZZY LOGIC

In this section, the proposed localization method is described in detail. A combination of two different Fuzzy systems, i.e. Sugeno [8] and Mamdani [16], is considered for locating the sensor node, based on the connectivity and RSSI.

3.1 Finding the Adjacent Reference Nodes using Connectivity

WSN consists of a set of anchor nodes and a set of sensor nodes. Anchor nodes are situated at known positions as (X_1, Y_1), (X_2, Y_2)…, (X_N, Y_N) and transmit periodic beacon signals containing their respective positions with overlap region of coverage. Sensor nodes are in the sensing field, with randomly distributed positions and locate themselves with the help of beacon signals, sent out by the anchor nodes. Each sensor node collects the RSS information of all adjacent anchor nodes through the strength of beacon signals. Following assumption are made for simulation setup [14],

- The anchor nodes know their positions through GPS or by other means such as pre-configuration.
- Neighboring anchor nodes are synchronized through time division multiplexing (TDM).
- The radio propagation is perfectly spherical and the transmission ranges for all radios are identical.

3.2 Calculating the Edge Weights using Fuzzy Inference System

3.2.1 Basic Theory and Rules for Edge Weights Calculation:

After collecting the RSSI values between the sensor node and anchor nodes, there is need to calculate edge weights for finding sensor node position. In this paper, fuzzy systems with symmetrical trapezoidal membership function for input (RSSI) and output (Weight), without optimization with GAs is used as compared to the membership functions used in [14] [15]. The fuzzy model composed of following rules:

Rule l: IF x is A^l THEN y is B^l

The input variable x is the RSS information from anchor node and takes a value in the interval $[0, RSS_{max}]$, where RSS_{max} is the maximum RSS value. The output variable y is the edge weight of each anchor node for a given sensor node and takes a value in the interval $[0, W_{max}]$, where W_{max} is the maximum weight.

Now, for modeling the FLS, the if-then rules need to be considered, which follow the basic principle that if a sensor node senses high powered signal from an anchor node then the anchor node is likely to be close to the given sensor node with high weight. Conversely, if a sensor node is connected to an anchor node but senses low powered signal, the anchor node is likely to be far from the given sensor node with a low weight. Consequently, the fuzzy rule bases are used to further tune the membership functions as shown in Table 1.

Table 1. Fuzzy logic rules for edge weight

Rule	IF: RSS is	THEN: Weight is
Rule 1	very low	very low
Rule 2	low	low
Rule 3	medium	medium
Rule 4	high	high
Rule 5	very high	very high

3.2.2 Edge Weight Calculation using Mamdani Fuzzy Inference System

In this method, the fuzzy logic system has been modeled using Mamdani fuzzy inference system and decomposes the input (RSS information) and output (Weight) space into five symmetrical trapezoidal membership functions namely: very low, low, medium, high, and very high, as shown in Figure 2 and 3. Edge weights are found out from the RSSI using Fuzzy membership function. Figure 4 gives the Edge Weight corresponding to the RSSI value for Mamdani Fuzzy system.

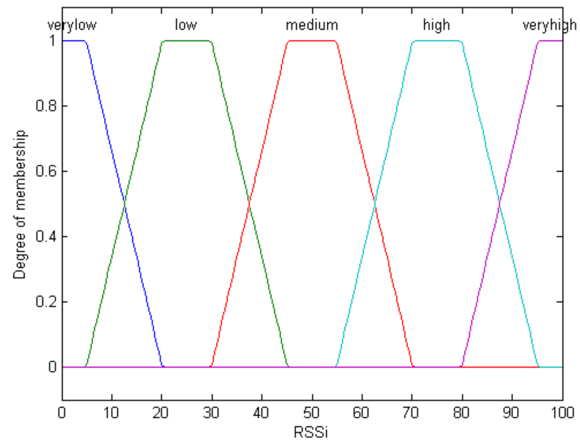

Figure 2. Fuzzy membership function of RSSI

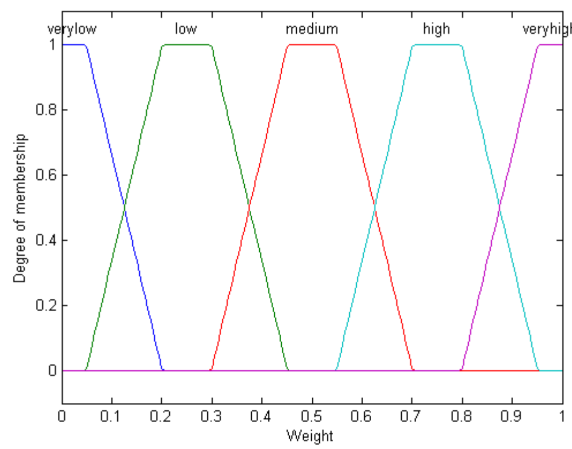

Figure 3. Fuzzy membership function of Weight

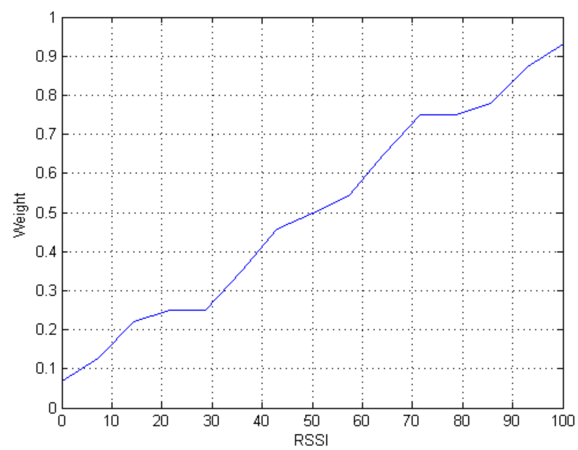

Figure 4. RSSI vs. Weight for Mamdani Fuzzy System

3.2.3 Edge Weight Calculation using Sugeno Fuzzy Inference System

In this method, the fuzzy system has been modeled using Sugeno method of fuzzy inference which is similar to the Mamdani method in many respects, introduced in 1985 [8]. The first two parts of the fuzzy inference process, fuzzifying the inputs, and applying the fuzzy operator, are exactly the same. The main difference between Mamdani and Sugeno is that the Sugeno output membership functions are either linear or constant. In this approach, liner output membership functions are considered. The input (RSS information) is decomposed into five symmetrical trapezoidal membership functions namely: very low, low, medium, high, and very high, as shown in Figure 5 and output (Weight) into five linear symmetrical functions namely: very low, low, medium, high, and very high. Sugeno systems do not have the output membership function plot. The defuzzification is considered to be weighted average. Figure 6 gives the Edge Weight corresponding to the RSSI value for Sugeno Fuzzy System.

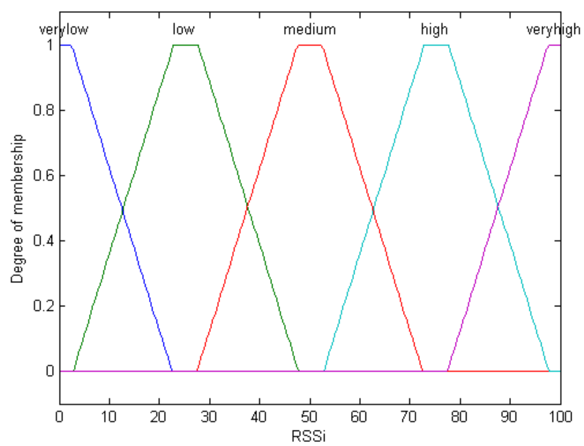

Figure 5. Fuzzy membership function of RSSI

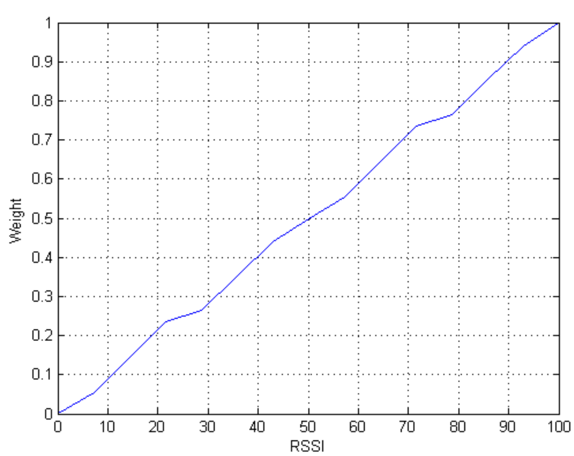

Figure 6. RSSI vs. Weight for Sugeno Fuzzy Inference System

3.3 Localization Algorithm

After calculating edge weights, the weighted centroid algorithm estimates the sensor node position, using the position of adjacent connected anchor nodes, let (X_1, Y_1), (X_2, Y_2)… (X_N, Y_N) respectively, then sensor node calculates its position as following weighted centroid formula [14] [15]:

$$(X_{est}, Y_{est}) = \left(\frac{w_1 \bullet X_1 + \ldots.. + w_N \bullet X_N}{\sum_{i=1}^{N} w_i}, \frac{w_1 \bullet Y_1 + \ldots. + w_N \bullet Y_N}{\sum_{i=1}^{N} w_i} \right) \quad (5)$$

where N is the number of connected adjacent anchor nodes.

3.4 Proposed Combined Mamdani-Sugeno Localization Approach

In the proposed approach the location estimation of sensor nodes are carried out by averaging the location estimation obtained from the Mamdani and Sugeno approach. Let the estimated node coordinates for Sugeno and Mamdani system are $(X_{est\text{-}sug}, Y_{est\text{-}sug})$ and $(X_{est\text{-}mam}, Y_{est\text{-}mam})$ respectively, then by the proposed combined approach, the estimated position of the sensor node can be found out as:

$$X_{est-final}, Y_{est-final} = \left(\frac{X_{est\text{-}sug} + X_{est\text{-}mam}}{2}, \frac{Y_{est\text{-}sug} + Y_{est\text{-}mam}}{2} \right) \quad (6)$$

where $(X_{est\text{-}final}, Y_{est\text{-}final})$ is the estimated position of sensor node.

3.5 Performance Evaluation

For evaluating the proposed schemes following two performance indices can be used [14]:

3.5.1 Location Error

The distance between the estimated position and the actual position of sensor node,

$$\text{Location Error} = \sqrt{(X_{est} - X_a)^2 + (Y_{est} - Y_a)^2} \quad (7)$$

where (X_{est}, Y_{est}) is the estimated position of sensor node while (X_a, Y_a) is the actual position of sensor node.

3.5.2 *Average Location Error*

The average distance between the estimated position and the actual position of all sensor nodes,

$$\text{Average Location Error} = \frac{\Sigma \sqrt{(X_{est} - X_a)^2 + (Y_{est} - Y_a)^2}}{\text{number of sensor nodes}} \quad (8)$$

4. SIMULATION TOOL AND ENVIRONMENT SETUP

MATLAB is used for performance evaluation of the simulation of the proposed scheme. Following primary network parameters are used for simulation: 60 sensor nodes distributed randomly, and 121 anchor nodes distributed uniformly in a square which has 100 meters length for each side. The transmission range of all anchor nodes is assumed 8.94 m. A sensor node will be in the proximity of adjacent anchor nodes if its distance from the anchor node is smaller than the transmission range. The following RSS model is used [14],

$$R_{ij} = (k d_{ij}^{-\alpha}) \quad (9)$$

where R_{ij} is the RSS value between the i^{th} sensor node and the j^{th} adjacent anchor node, k is a constant which takes into account carrier frequency and transmitted power, d_{ij} is the distance between the i^{th} sensor node and the j^{th} adjacent anchor node and α is the attenuation exponent. Here we use k = 50 and α = -1 [14].

5. SIMULATION RESULTS

In this paper, the four localization methods are implemented for comparison: 1) Simple Centroid Approach [9], 2) Mamdani Fuzzy Approach, 3) Sugeno Fuzzy Approach, and 4) A Combined Mamdani-Sugeno Approach. Figures 7 to 14 show the result of location estimation and localization error of these methods respectively.

5.1 Simulation Results for Localization using Simple Centroid Approach

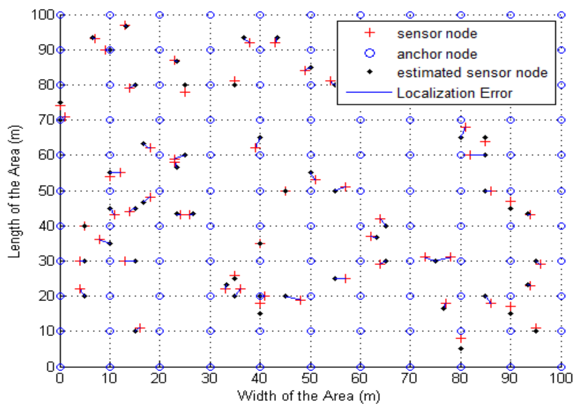

Figure 7. Result of location estimation

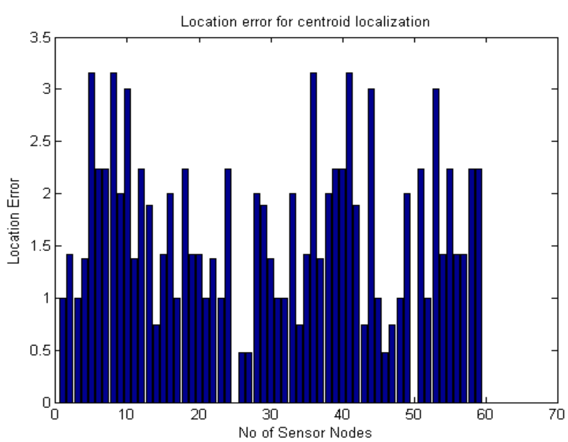

Figure 8. Result of localization error (m)

5.2 Simulation Results for Localization using Mamdani Fuzzy Approach

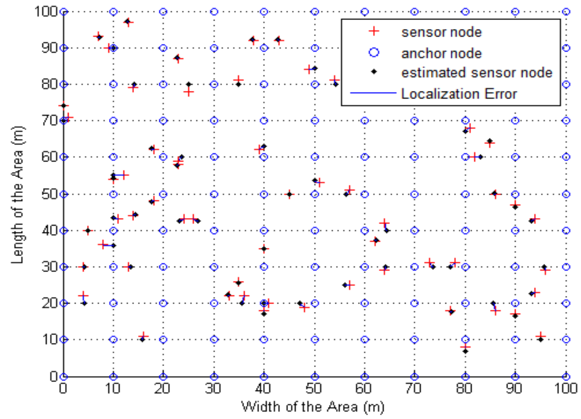

Figure 9. Result of location estimation

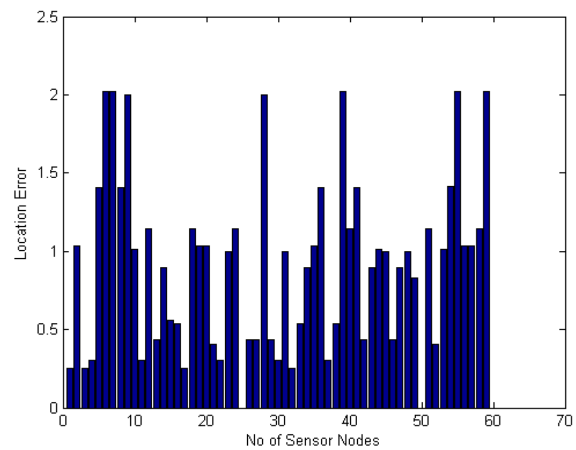

Figure 10. Result of localization error (m)

5.3 Simulation Results for Localization using Sugeno Fuzzy Approach

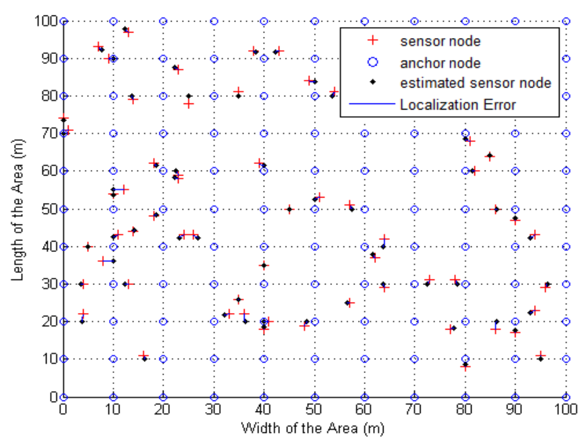

Figure 11. Result of location estimation

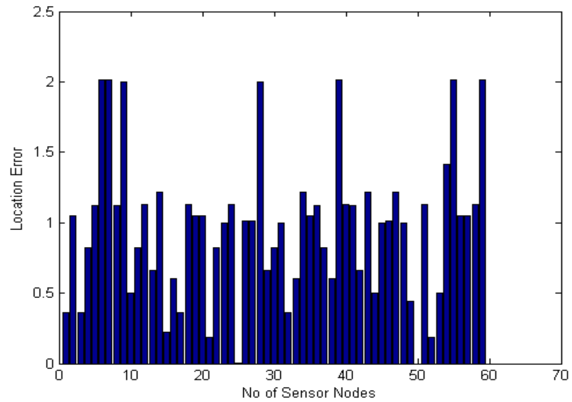

Figure 12. Result of localization error (m)

5.4 Simulation Results for Localization using Combined Mamdani-Sugeno Approach

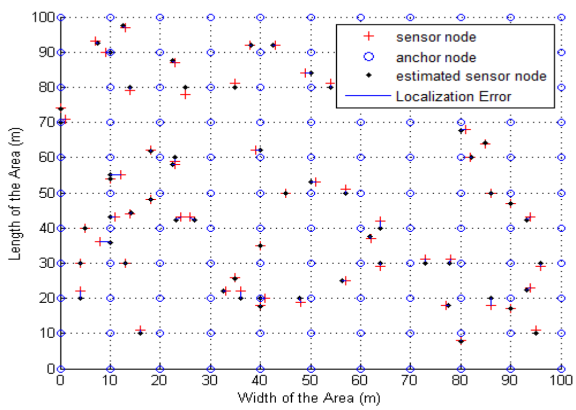

Figure 13. Result of location estimation

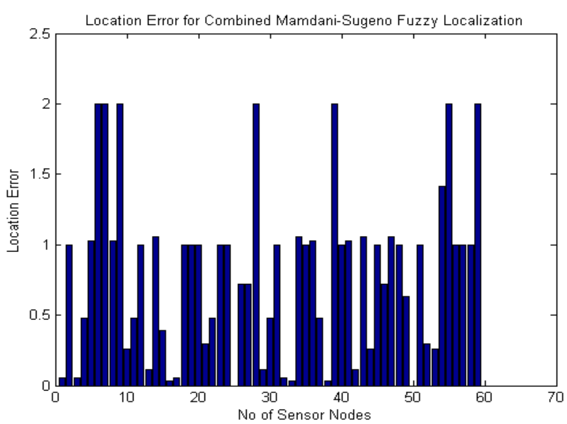

Figure 14. Result of localization error (m)

The plus (+) sign denote the actual position of sensor nodes and the points (.) denote the estimated position of sensor nodes in the first sub-figure of Figures 7–14. In the second sub-figure of Figures 7–14 the solid bars denote the location estimation error for each sensor node. The simulation results are summarized in Table 2.

Table 2. Comparison results for different approaches

Approachs	Max. error (m.)	Min. error (m.)	Avg. error (m.)
Simple Centroid	3.1623	0	1.6080
Mamdani Fuzzy	2.0211	0	0.8956
Sugeno Fuzzy	2.0108	0	0.9462
Combined Mamdani-Sugeno	2.0004	0	0.7891

6. OPTIMIZED BEACONS RANGE CALCULATION

The result from Table 2 established that the proposed approach is very effective and accurate, and can be made more effective by taking account of the optimized beacons transmission range. However, the effectiveness and accuracy of the proposed approach depends upon the signal strength of anchor nodes, which in turn decide the beacon range. Simulation is carried out to establish a relationship between beacon range and average localization error for discussed approaches including the proposed one. The simulation result is shown in Figure 15. The result of simulation can be used to establish the optimum beacon range for maximum localization accuracy.

As the power requirement is directly proportion to the beacon range, the beacon range can be categorized as "Low Beacon Range (<=10 m)" and "High Beacon Range (>10 m)". Table 3 and 4 give the result of average localization error with optimum beacon range for various approaches including the proposed one for Low and High beacon range respectively. The analysis shows that for low beacon range, the best approach is the proposed one with optimum beacon range of 10 meter. Figure 16 shows the localization error of Combined Mamdani-Sugeno approach for optimized beacon range of 10 meter. For beacon range >10 meter the Sugeno approach is showing the best location accuracy for optimum beacon range of 13 meter. Figure 17 and 18, show location error for the Sugeno and Combined Mamdani-Sugeno approaches for optimized beacon range of 13 meter.

Table 3. Comparison result of optimum beacon range and corresponding average localization error (Range<=10m)

Approaches	Optimum Beacon Range (For Range <=10m)	Average Location Error (m)
Simple Centroid	9	1.645952
Mamdani Fuzzy	10	0.751065
Sugeno Fuzzy	10	0.59465
Combined Mamdani-Sugeno Fuzzy	10	0.518963

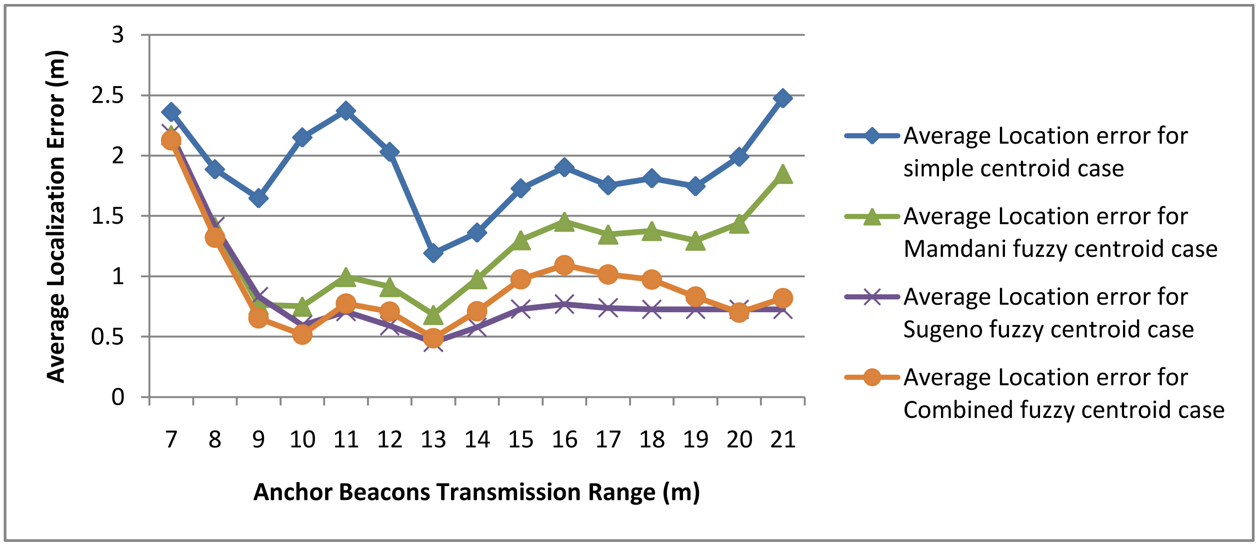

Figure 15. Average localization Error vs. beacons transmission range

Table 4. Comparison result of optimum beacon range and corresponding average location error (Range>10m)

Approaches	Optimum Beacon Range (For Range >10m)	Average Location Error (m)
Simple Centroid	13	1.191188
Mamdani Fuzzy	13	0.682622
Sugeno Fuzzy	13	0.453774
Combined Mamdani-Sugeno Fuzzy	13	0.488849

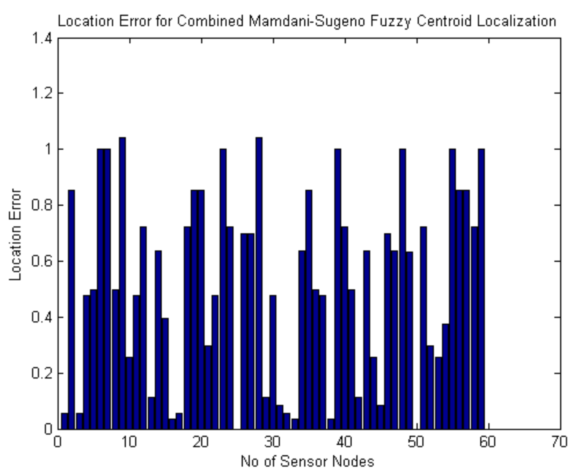

Figure 16. Result of localization error (m) for Combined Mamdani-Sugeno approach (beacon range of 10 m).

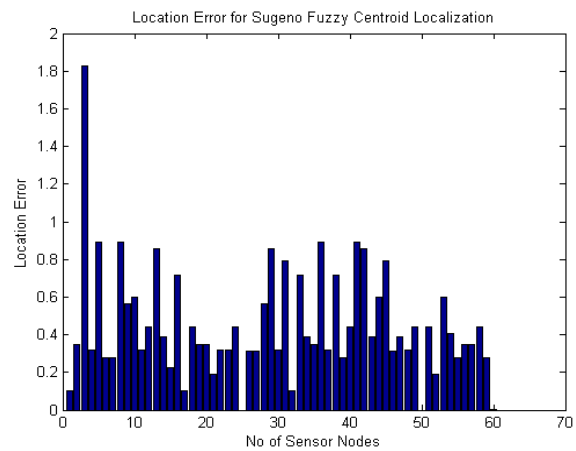

Figure 17. Result of localization error for Sugeno approach (beacon range of 13 m).

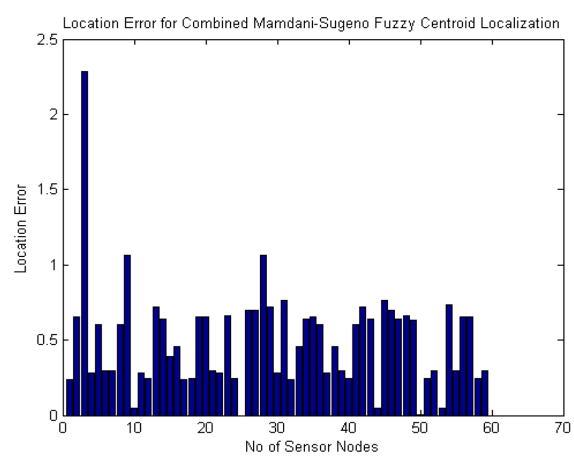

Figure 18. Result of localization error (m) for Combined Mamdani-Sugeno approach (beacon range of 13 m).

7. CONCLUSION

In this paper, Combined Mamdani-Sugeno approach has been used to minimize the localization error using range free method. Further minimization in localization error has been carried out by finding the optimum signal strength (range) of anchor nodes. The RSS information between sensor nodes and its neighbor anchor nodes is used to estimate the positions without any complicated hardware. Fuzzy logic system is the main component of the proposed schemes. First of all, the edge weight of each anchor node which is adjacent and within the range the sensor node, are found out using Mamdani fuzzy system and the weighted centroid theorem is applied to estimate the sensor node position, then the edge weights are calculated using Sugeno fuzzy system and the localization of node is carried out by weighted centroid theorem. Proposed Combined Mamdani-Sugeno approach, localize the node by taking the average of the location obtained from first two schemes.

The above mentioned approaches are simulated using MATLAB. The proposed combined Mamdani-Sugeno approach shows, improved performance compared to the existing approaches i.e. simple centroid and non optimized fuzzy approaches as discussed, and comparable performance to that of the optimized fuzzy system using GAs. This approach can be applied for large scale network to estimate node positions independently. It is better to use optimized beacon transmission range to minimize the localization error. This optimized beacon range value has been found out using simulation results and can be implemented in real time environment. As higher transmission range required high battery power, a lower value of optimized range must be taken while implementing the localization in real scenario.

8. REFERENCES

[1] A. Pal 2010. Localization Algorithms in Wireless Sensor Networks: Current Approaches and Future Challenges. *Network Protocols and Algorithms* 2, 1 (March 2010), 45-73, ISSN 1943-3581.

[2] A. Savvides, C. Han, and M. B. Strivastava 2001. Dynamic Fine-Grained Localization in Ad-hoc Networks of Sensors. *Proceedings of the seventh annual international conference on Mobile computing and networking (MobiCom 01)*, (Rome, Italy, July 2001), 166-179. DOI= http://doi.acm.org/10.1145/381677.381693.

[3] C. Chong and S. P. Kumar 2003. Sensor Networks: Evolution, Opportunities, and Challenges. *Proceedings of the IEEE* 91, 8 (August 2003), 1247-1256.

[4] D. Niculescu and B. Nath 2003. DV Based Positioning in Ad hoc Networks. *Journal of Telecommunication Systems* 22, 1 (January 2003), 267-280.

[5] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci 2002. Wireless sensor networks: a survey. *Computer Networks* 38, 4, (March 15, 2002), 393–422.

[6] Kim, S. Y., & Kwon, O. H. 2005. Location estimation based on edge weights in wireless sensor networks. *Journal of Korea Information and Communication Society* 30, 10A (2005).

[7] L. Girod and D. Estrin 2001. Robust Range Estimation using Acoustic and Multimodal Sensing. *Proceedings of IROS 2001*, 3 (October 2001), 1312-1320.

[8] M. Sugeno. An introductory survey of fuzzy control. *Information Sciences* 36, 1-2 (July-August 1985), 59-83.

[9] N. Bulusu, J. Heidemann and D. Estrin 2000. GPS-less Low Cost Outdoor Localization for Very Small Devices. *IEEE Personal Communication Magazine* 7, 5 (October 2000), 28-34.

[10] P. Bahl and V. N. Padmanabhan (2000). RADAR: An In-Building RF-Based User Location and Tracking System. *Proceedings of the IEEE Infocom 2000*, 2 (March 26-30, 2000), 775-784.

[11] S. Meguerdichian, F. Koushanfar, M. Potkonjak, and M.B. Srivastava 2001. Coverage Problems in Wireless Ad-hoc Sensor Networks. *Proceedings of IEEE lnfocom 2001* 3 (April 22-26, 2001), 1380-1387.

[12] T. He, C. Huang, B.M. Blum, J. A. Stankovic, and T. Abdelzaher 2003. Range-Free Localization Schemes for Large Scale Sensor Networks. *Proceedings of the ninth annual international conference on Mobile computing and networking (MobiCom 2003)*, (San Diego, CA, USA, September 2003), 81-95. DOI= http://doi.acm.org/10.1145/938985.938995.

[13] Y. B. KO and N. H. Vaidya 1998. Location-Aided Routing (LAR) Mobile Ad Hoc Networks. *Proceedings of the fourth annual international conference on Mobile computing and networking (MobiCom 98)*, Dallas, Texas, (October 1998), 66-75. DOI= http://doi.acm.org/10.1145/288235.288252.

[14] Y. Sukhyun, L. Jaehun, and Wooyong 2009. A soft computing approach to localization in wireless sensor networks. *Expert Systems with Applications* 36, 4 (May 2009), 7552–7561.

[15] Yun, S., Lee, J., Chung,W., & Kim, E. 2005. Centroid localization method in wireless sensor networks using TSK fuzzy modeling. *International symposium on advanced intelligent systems*, (Sokcho, Korea, September 2005), 971–974.

[16] Mamdani, E.H.1977. Applications of fuzzy logic to approximate reasoning using linguistic synthesis. *IEEE Transactions on Computers* 26, 12 (December 1977), 1182-1191.