Range Free Localization Schemes For Wireless Sensor Networks

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Abstract: - Wireless Sensor Networks (WSNs) are being used for a large number of location-dependent applications, where the measurement data is meaningless without accurate location of its origin. In many of these applications, where coarse accuracy is sufficient, range free localization techniques are being pursued as low cost alternative to the range based localization techniques. Localization in WSNs is to determine the physical position of a sensor node based on the known positions of other sensor nodes having a priori knowledge of their position. In this paper, we present range free Adaptive Neural Fuzzy Inference System (ANFIS) trained Sugeno weighted centroid localization and combined Mamdani-Sugeno fuzzy localization methods. In the proposed techniques the weights of anchor nodes are obtained either through ANFIS trained Sugeno fuzzy inference system or by combined Mamdani-Sugeno fuzzy inference approach. We compared the proposed techniques, through extensive simulation with simple centroid, Mamdani and Sugeno fuzzy methods. The simulation results demonstrate the effectiveness of proposed schemes.

Key-Words: - Centroid localization, Edge weight, Fuzzy logic system, Range-free localization, Wireless sensor networks.

1 Introduction

Wireless sensor networks (WSNs) is an emerging and promising technology for ubiquitous sensing, monitoring and controlling home, office, city and environment for large number of applications [1]. Recent advances in wireless communications and electronics has enabled the development of low cost, low power and multifunctional sensors, which when networked wirelessly provide broad spectrum of applications in defense, habitant monitoring, target tracking and traffic monitoring etc. [3, 5]. Localization (location estimation) capability is essential in most of the WSN applications, where the measurement data is meaningless without the knowledge of precise location from where it is obtained. WSN localization techniques are used to estimate the location of sensor nodes in the network using a priori knowledge of location of few specific sensor nodes in the network, known as anchor nodes. The anchor nodes can obtain their location using global positioning system (GPS), or by placement of anchor nodes at points with known coordinates. In applications requiring global coordinate systems, the anchors determine the location of sensor nodes with reference to the global coordinate system and the application where a local coordinate system is sufficient, the position of sensors are referred to the local coordinate system of network. Many localization algorithms have been proposed in literature for location estimation of sensor nodes in WSNs. The 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 is defined by protocols that use absolute point-to-point distance estimates (range) or angle estimates for calculating the location. These methods utilize the measurement such as angle of arrival (AOA), time of arrival (TOA), time difference of arrival (TDOA) and received signal strength (RSS) profiling. In contrast, range-free localization schemes make no assumption about the availability or validity of such information. Normally range-based schemes have higher location accuracy than the range-free localization schemes, but are hardware intensive [2]. Because of the hardware limitations of WSN devices, solutions in range-free localization are being pursued as a cost-effective alternative to more expensive range-based approaches. Bulusu et al. proposed a simple and economic range free localization technique, based on proximity based centroid algorithm [9]. In this method the sensor node localizes itself by calculating the centroid of position of all the adjacent connecting anchor nodes. Though simple and economic, the localization estimates of this method are quite poor with large error in measurement. To improve the performance of centroid algorithm, an enhanced weighted centroid algorithm was proposed by Kim and Kwon [6]. The method provides good accuracy in localization. But the accuracy of localization depends upon optimized selection of edge weights, which are selected heuristically in the proposed method. Y.Sukhyun et al. used TSK fuzzy modeling for calculating the weights of anchor nodes [15]. In this method, genetic algorithm is used to optimize the fuzzy membership function to obtain optimized edge weight based on the received signal strengrh (RSS). Y. Sukhyun et al. also proposed neural network approach for calculation of weights for centroid algorithm [14]. Both of these approaches provide acceptable accuracy in localization of sensor nodes. But the computational complexity is quite high for resource constrained sensor nodes.

In this paper we propose range free localization techniques for WSNs based on weighted centroid algorithm. The weights of anchor nodes have been obtained based on the received signal strength information (RSSI), which requires no additional hardware in sensor node as it is available as part of physical layer of sensor node. In first proposed localization technique (ANFIS trained Sugeno weighted centroid localization technique) fuzzy membership functions have been optimized using ANFIS trained Sugeno fuzzy inference system to calculate the weight of anchor nodes and further weighted centroid method has been used to obtain the localization information of sensor node. Second proposal consists of localization scheme (Combined Mamdani-Sugeno Fuzzy Approach for Localization), wherein the edge weight of anchor node is calculated by averaging the edge weights obtained from Sugeno and Mamdani fuzzy approach.

Rest of this paper is organized as follows: In Section 2, centroid localization, weighted centroid localization and fuzzy logic system is introduced. In Section 3, proposed localization techniques are presented. In Section 5, simulation environment and results are discussed. Finally, conclusions are drawn in Section 5.

2 BACKGROUND

2.1 Centroid localization

Centroid localization technique uses the knowledge of adjacent connected anchor node position (X_i, Y_i) to estimate the location of sensor node [9]. In this method, the anchor nodes transmit a beacon containing their respective location information. The sensor node computes its position as centroid of the positions of all the adjacent connected anchor nodes to itself

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

where (X_{est}, Y_{est}) represents the estimated position of the sensor node and N is the number of adjacent connected anchor nodes to the sensor node. The method of location estimation using centroid algorithm is very simple and economic, but the results shows that location estimation error is very large in this method and is unacceptable in case of application requiring accurate localization of sensor nodes.

An improved version of centroid algorithm is weighted centroid method [6]. In this method, location of sensor node is calculated by edge weights of anchor nodes connected to the sensor node, and each sensor node computes its position by:

$$(X_{est}, Y_{est}) = \left(\frac{w_1 \bullet X_1 + \ldots.. + w_n \bullet X_n}{\sum_{i=1}^{n} w_i}, \frac{w_1 \bullet Y_1 + \ldots. + w_n \bullet Y_n}{\sum_{i=1}^{n} w_i} \right) \quad (2)$$

where w_i is the edge weight of i^{th} anchor node connected to the sensor node. The edge weight is decided based upon the proximity of anchor node to the sensor node. Performance of this approach highly depends on the optimization of edge weights.

2.2 Fuzzy logic system

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. The process of fuzzy inference involves the Membership Functions, Logical Operations, and If-Then Rules. Fuzzy logic inference system is very simple approach for designing of edge weights for anchor nodes [14, 15]. A fuzzy logic system consists of a fuzzifier, some fuzzy IF–THEN rules, a fuzzy inference engine and a defuzzifier. Fuzzy inference system can be implemented in two ways: Mamdani-type and Sugeno-type. These two types of inference systems vary somewhat in the way the outputs are determined. The main difference between Mamdani and Sugeno is that the Sugeno output membership functions are either linear or constant.

3 LOCALIZATION USING FLS

This section describes the proposed localization methods in detail. We have considered two different fuzzy systems (Sugeno and Mamdani) for locating the sensor nodes. In one of the proposed approaches, the edge weights obtained in Sugeno fuzzy inference method are optimized by using ANFIS training to calculate the weight of anchor nodes and further weighted centroid method is used to obtain the localization information of sensor node. In case of Combined Mamdani-Sugeno Fuzzy Approach, the edge weight of anchor node is calculated by averaging the edge weight obtained from Sugeno and Mamdani fuzzy approach. Received signal strength information (RSSI) of adjacent connected anchor nodes has been used to obtain the weight of anchor node and further to find edge weights using fuzzy modeling between the sensor node and anchor nodes.

3.1 Finding the adjacent reference nodes

WSN consists of a set of sensor nodes deployed randomly in vast area to monitor the parameters of interest. These nodes can be categorized as: anchor nodes and normal sensor nodes. Anchor nodes are special type of nodes embedded with GPS or other facility to obtain their position with in the network. If feasible these nodes can also be placed manually at known positions with in the network. . The position of anchor nodes is assumed as (X_1, Y_1), (X_2, Y_2),…,(X_n, Y_n). Anchor nodes transmit periodic beacon signals containing their respective positions with overlapped region of coverage. Sensor nodes are deployed in the sensing field, with randomly distributed positions. These sensor nodes locate themselves with the help of beacon signals, transmitted by the anchor nodes. Each sensor node collects the RSS information of all connected adjacent anchor nodes through beacon signal and RSSI is used to obtain the edge weight of the anchor node for weighted centroid localization. Following assumptions have been made:

- The anchor nodes know their positions through GPS or by other means such as pre-configuration.
- TDM technique is used to avoid interference of beacons transmitted by anchor nodes.
- 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

The sensor node collects the received signal strength indication (RSSI) values between the sensor node and anchor nodes. The edge weights of anchor nodes need to be calculated for finding sensor node position. In this paper, fuzzy systems with symmetrical trapezoidal membership function for input (RSSI) and output (Weight) has been used. The fuzzy model is 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.

For modeling the fuzzy logic inference system (FLS), if-then rules have to be considered, which follow the basic principle that if a sensor node senses high powered signal from an anchor node, the anchor node is likely to be in close proximity to the given sensor node and hence is assigned 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 and hence is assigned a low weight. Consequently, we used the fuzzy rule bases and tuned the membership functions [14, 15] 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 localization method, fuzzy logic system has been modeled using Mamdani fuzzy inference system. The input (RSS information) and output (Weight) space have been decomposed into five symmetrical trapezoidal membership functions namely: very low, low, medium, high, and very high, as shown in Fig. 1 and 2.

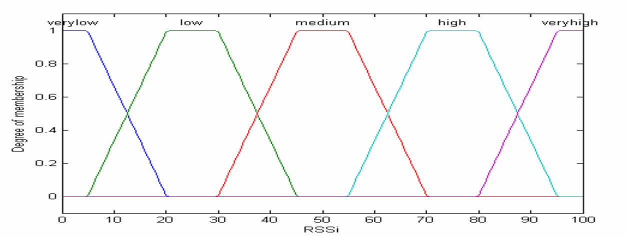


Fig. 1. Fuzzy membership function of RSSI

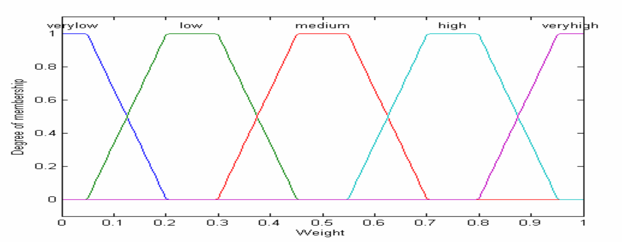


Fig. 2. Fuzzy membership function of Weight

3.2.3 Edge weight calculation using Sugeno fuzzy inference system

In this method, fuzzy system has been modeled using Sugeno method of fuzzy inferenc [8], it is similar to the Mamdani method in many respects. 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 our approach we have considered liner output membership function and have decomposed the input (RSS information) into five symmetrical trapezoidal membership functions namely: very low, low, medium, high, and very high, as shown in Fig. 3. The output has been decomposed 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.

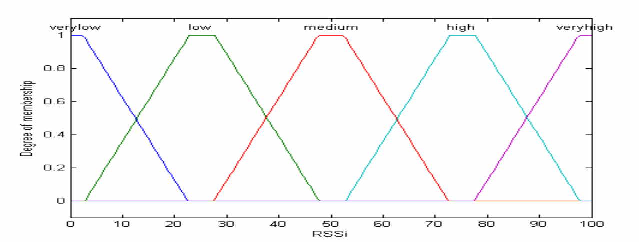


Fig. 3. Fuzzy membership function of RSSI

3.3 Weighted localization algorithm

After calculating edge weights using Sugeno or Mamdani fuzzy inference system, the weighted centroid algorithm is used to estimate the sensor node position, using the position of adjacent connected anchor nodes (X_1, Y_1), (X_2, Y_2)… (X_n, Y_n) respectively. Non anchor sensor node calculates its position as per following weighted centroid formula [14, 15]:

$$(X_{est}, Y_{est}) = \left(\frac{w_1 \cdot X_1 + \ldots.. + w_n \cdot X_n}{\sum_{i=1}^{n} w_i}, \frac{w_1 \cdot Y_1 + \ldots. + w_n \cdot Y_n}{\sum_{i=1}^{n} w_i} \right) \quad (5)$$

where n is the number of adjacent connected anchor nodes.

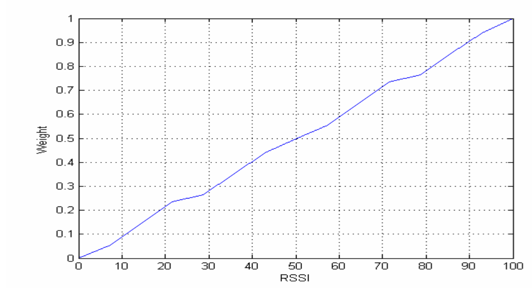
3.4 Proposed ANFIS trained Sugeno fuzzy system

The acronym ANFIS derives its name from adaptive neuro-fuzzy inference system. Using a given input/output data set, ANFIS can construct a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted) using either a back propagation algorithm alone or in combination with a least squares type method. This adjustment allows our fuzzy systems to learn from the data we are modeling [16, 17]. In our approach, the Sugeno fuzzy inference system is trained using the ANFIS, which model the system to get the linear edge weight related to the RSS information as shown in Fig. 4. Fig. 3.

3.5 Proposed CMS Localization Approach

A combinded Mamdani-Sugeno localization approach has been proposed for calculating the sensor node position. If 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 the estimated position of sensor node can be calculated by taking the average of coordinates as per the following formula:

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



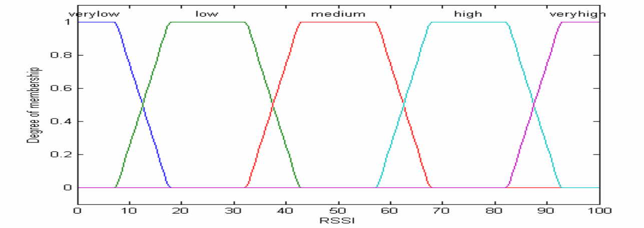


Fig. 6. ANFIS trained fuzzy membership function of RSSI

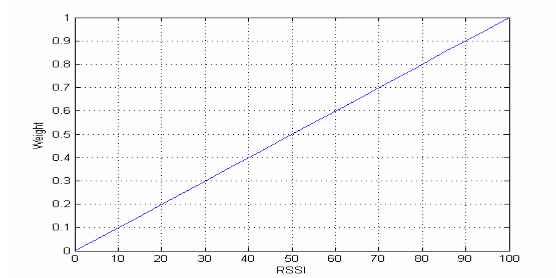


Fig. 5. RSSI vs. Weight for trained Sugeno fuzzy system

3.6 Performance evaluation

For evaluating the proposed schemes and comparing with existing methods, following two performance indices have been used:

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

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

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

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

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

4 SIMULATION AND RESULTS

MATLAB has been used for performance evaluation of the proposed schemes in the simulation experiments with following primary network parameters:

60 sensor nodes with unknown position and 121 anchor nodes with known position are distributed randomly with in 10mX10m area. The transmission range of all anchor nodes is assumed to be 8.94 m. A sensor node is assumed to be in the proximity of adjacent anchor nodes if its distance from the anchor node is smaller than the transmission range. We used the following RSS model [14].

$$R_{ij} = (kd_{ij}^{-\alpha}) + (AWGN*Var) \quad (9)$$

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 have used k = 50 and α = -1 [14].

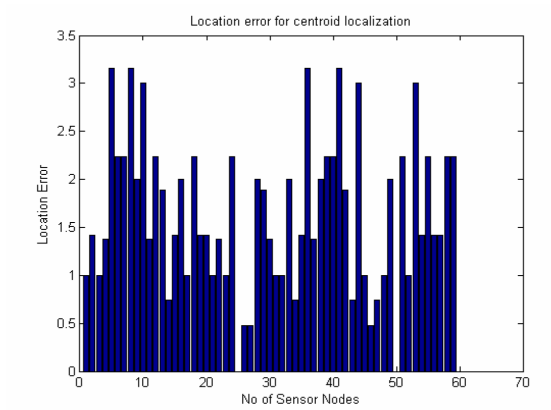


Fig. 7. Localization error for simple centroid method

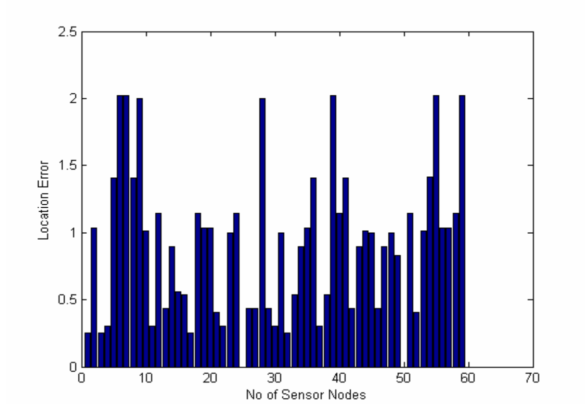


Fig. 8. Localization error for Mamdani FLI

In this paper, we have simulated three existing localization techniques for comparison with two proposed localization techniques. Same simulation set-up has been used for all the techniques for comparison of results. Following localization techniques have been simulated : A) the simple centroid approach, B) the Mamdani fuzzy approach, C) the Sugeno fuzzy approach, D) ANFIS trained Sugeno fuzzy approach and E) a combined Mamdani-Sugeno approach. Fig. 4 to 11 show the result of location estimation and localization error of these methods respectively. Table 2 shows the comparison of different algorithms.

Table 2. Comparison of Simulation Results

Approaches	**Max. error (cm.)**	**Avg. error (cm.)**
Simple centroid	316.23	160.80
Mamdani FLI	202.11	89.56
Sugeno fuzzy	201.08	94.62
ANFIS trained Sugeno FLI	200.50	76.64
Combined M- S FLI	200.04	78.91

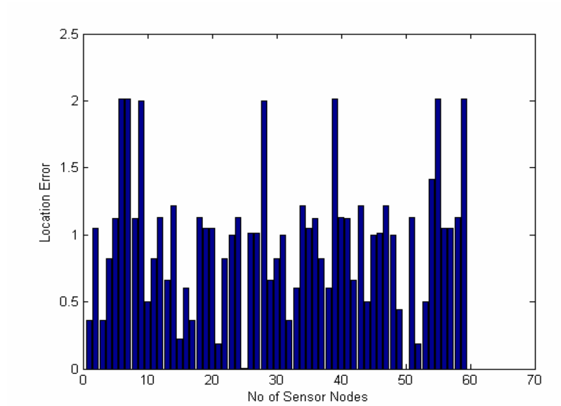


Fig. 9. Localization error for Sugeno FLI

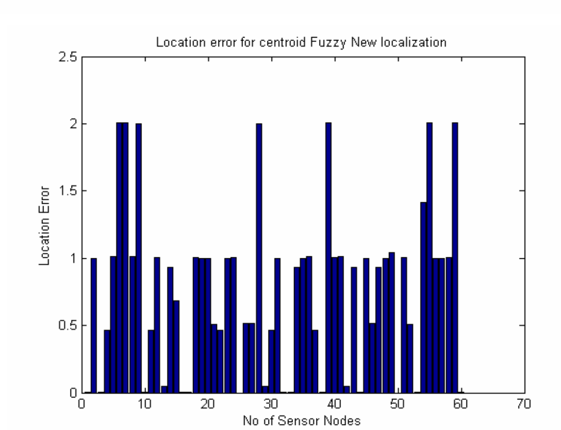


Fig. 10. Location error for ANFIS trained Sugeno FLI

5. CONCLUSION

Given the inherent constrains of the sensor devices and estimation accuracy desired by location dependent application, range free localization are regarded as cost effective solution for sensor node localization. In this paper, two range free localization methods have been proposed for wireless sensor networks (WSNs). The

RSS information between sensor nodes and its neighbor anchor nodes can be used to estimate the positions without any complicated hardware. Fuzzy logic system is the main component of our proposed schemes.

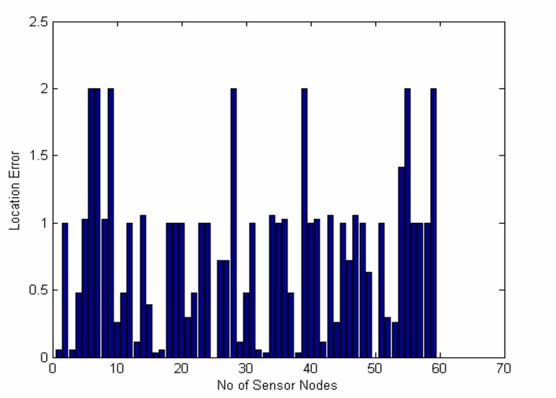


Fig. 11. Localization error for combined M-S FLI

In the first scheme, we find the edge weight of each anchor nodes using ANFIS trained Sugeno fuzzy inference. In second approach, which is less computation intensive, a combined Mamdani and Sugeno fuzzy system is used to determine the edge weight of anchor node and to enhance the location estimation accuracy of sensor nodes in the sensor network. The proposed approaches are simulated using MATLAB. The results have been compared with existing techniques through extensive simulations. Simulation results demonstrate the effectiveness of the proposed schemes in comparison to the previous methods.

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