Localization in Wireless Sensor Networks Based on Fuzzy Logic

Mostafa Arbabi Monfared

Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the Degree of

Master of Science
in
Electrical and Electronic Engineering

Eastern Mediterranean University
January 2012
Gazimağusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

Prof. Dr. Elvan Yılmaz
Director

I certify that this thesis satisfies the requirements as a thesis for the degree of Master of Science in Electrical and Electronic Engineering.

Assoc. Prof. Dr. Aykut Hocanın
Chair, Department of Electrical and Electronic Engineering

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Electrical and Electronic Engineering.

Prof. Dr. Şener Uysal
Supervisor

Examining Committee

1. Prof. Dr. Şener Uysal
2. Assoc. Prof. Dr. Hasan Demirel
3. Assist. Prof. Dr. Rasime Uyguroglu

ABSTRACT

One of the fundamental problems in Wireless Sensor Networks (WSNs) is the localization of sensor nodes based on the known location of several nodes. In this thesis one of the intelligent localization schemes, which is a range free localization is used to estimate the location of the unknown nodes. In the proposed method, the anchor nodes (reference nodes) are connected to the sensor nodes and then each sensor node receives the signal strength indicator (RSSI) from each of the anchor nodes. The RSSIs are achieved based on the distance of the sensor node to each of anchor nodes.

The RSSIs are fed to the sugeno fuzzy inference system to calculate the weights used in the centroid relation. The centroid technique is the range free based localization scheme, which is proposed to estimate the location of the sensor nodes. Both analytical and experimental approaches are considered where the analytical approach is done by sugeno fuzzy inference in the two different environments with and without Additive White Gaussian Noise (AWGN).

The experimental method is done for 6 sensor nodes and repeated 6 times in different positions in a region. There is an error of locating the actual and the estimated nodes in both analytical and experimental approaches. The error of location of the estimated sensor nodes in the experimental method is not much in comparison with the analytical method.

Keywords: Range free localization, received signal strength indicator, centroid localization, fuzzy logic system and wireless sensor network.

ÖZ

Kablosuz Sensör Ağları (KSA) (“Wireless Sensor Networks” – WSNs -) konusunda yaşanmakta olan temel sorunlardan biri, bilinen birkaç sensör düğümünün konumlarına istinaden sensör düğümlerinin lokalizasyonudur. Bu tez çalışmasında, bilinmeyen sensör düğümlerinin konumlarının tahmin edilmesi amacıyla, uzaklığa bağlı olmayan bir lokalizasyon yöntemi olan akıllı lokalizasyon planlarından biri kullanılmaktadır. Önerilmekte olan yöntemde, referans sensör düğümleri diğer sensör düğümlerine bağlanmakta ve bundan sonraki aşamada her bir sensör düğümü Sinyal Güç Göstergesini (SGG) (“Signal Strength Indicator” – RSSI -) her bir referans düğümünden almaktadır. Elde edilen Sinyal Güç Göstergeleri, sensör düğümünün her bir referans sensör düğümünden uzaklığına bağlı olmaktadır.

Elde edilen Sinyal Güç Göstergeleri, ağırlık merkezi hesaplama bağıntısında kullanılmak amacıyla ağırlıkları hesaplanmak üzere Sugeno bulanık hesaplama ve sonuçlandırma sistemine verilmektedir. Ağırlık merkezi hesaplama tekniği, sensör düğümlerinin konumlarının tahmin edilmesi için önerilen ve uzaklığa bağlı olmayan baz lokalizasyon tekniklerinden biri olmaktadır.

Bu çalışmada hem analitik hem de deneysel yöntemler dikkate alınmış olup analitik incelemeler, Beyaz Gauss Gürültülü (BGG) (“Additive White Gaussian Noise” – AWGN -) ve Beyaz Gauss Gürültüsüz olmak üzere iki değişik ortamda Sugeno Hesaplama ve Sonuçlandırma Sistemi tarafından gerçekleştirilmiştir.

Deneyler 6 sensör düğümü için yapılacak olup bir alandaki 6 farklı konumda tekrarlanacaktır. Hem analitik hem deneysel incelemeler sırasında düğümlerin gerçek konumları ile tahmin edilen konumları arasında bir hata bulunmaktadır. Deneysel çalışmalarda tahmin edilen her bir sensör düğümünün konumu ile gerçek

düğüm konumu arasındaki fark analitik incelemeler ile karşılaştırıldığında çok büyük farklılıklar görülmamaktedır.

Anahtar Kelimeler: Uzaklığa bağlı olmayan lokalizasyon, Gelen sinyal güç göstergesi, ağırlık merkezi lokalizasyonu, bulanık mantık sistemi ve kablosuz sensör ağı

Dedicated to

Baran

My parents, brother and sister

ACKNOWLEDGMENTS

I take this opportunity to thank my supervisor Prof. Dr. Şener Uysal for guiding me all along my thesis research.

I wish to sincerely thank my friend Reza Abrishambaf who kindly shared his knowledge and experiences with me.

I also wish to thank all the faculty members at the department of Electrical and Electronic Engineering, and specially the chairman, Assoc. Prof. Dr. Aykut Hocanın.

Last but not least, I would like to express my deepest appreciation to my family who allowed me to travel to Cyprus and supported me during my study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AOA	Angle of Arrival
APIT	Approximate Point in Triangle
ASIC	Application Specific Integrated Circuit
AWGN	Additive White Gaussian Noise
DOA	Direction of Arrival
FIS	Fuzzy Inference System
FL	Fuzzy Logic
H	High
GPS	Global Positioning System
L	Low
M	Medium
MCU	Microcontroller Unit
MDS	Multi Dimensional Scaling
MEMS	Micro Electro Mechanical System
MH	Medium High
ML	Medium Low
PIT	Point in Triangulation
QOS	Quality of Service
RSS	Receive Signal Strength
RSSI	Receive Signal Strength Indicator
SNR	Signal to Noise Ratio
TDOA	Time Different of Arrival
TOA	Time of Arrival

V	Velocity
VH	Very High
VL	Very Low
VVH	Very Very Low
VVL	Very Very Low
WLAN	Wireless Local Area Network
WSN	Wireless Sensor Network

Chapter 1

INTRODUCTION

1.1 Overview

Wireless Sensor Networks consist of unique nodes, which are small, battery powered devices that can compute and communicate different signals in an environment. The WSNs have many applications in buildings, air traffic control, manufacturing automation, environment monitoring, industry and security [1].

Recently, wireless sensor networks are used in different environments to obtain various tasks such as, disaster relief, target tracking and also a number of tasks in smart environments. Node localization is needed to report in different situations such as the origin of events, assist group querying of sensors and also to answer the questions on the network coverage. Hence node localization becomes a fundamental challenge in wireless sensor networks.

The developments of micro electro mechanical systems (MEMS), communication technology and computing have motivated a massive advancement in distributed wireless sensor networks, which consist of hundreds or thousands of nodes. In these architectures every node is able to sense the environment, compute and communicate with central unit or other sensors [2].

1.2 Definition of Problem

Wireless Sensor Networks are particularly attractive in risky environments, specifically where a large deployment is required. In WSN applications, one of the key problems is the location of the unknown sensor nodes for the base service. It is very important in system design to compute the correct position of the sensor node in some coordinate system.

There are two kinds of nodes in WSNs, namely anchor nodes, and unknown sensor nodes. Some sensor nodes are aware about their positions, which are called anchor or beacon. Anchor nodes contain energy and accurate information about their position. However, unknown sensor nodes don't have those specifications. One of the most significant problems in WSNs is the localization of the unidentified sensor nodes for the location based on service and plays an important role for different application scenarios in WSNs [16].

Some studies have been reported about localization in WSNs which can be divided into two classes: range based and range free schemes, which are different in the information used for localization. Range based schemes are more accurate and are important in applications such as target tracking and localization. On the other hand, the range free scheme can be simplified due to hardware design where only anchor nodes needed to have knowledge about their locations [18].

1.3 Decision Making Process

The range free localization method is very simple due to not requiring any complicated hardware. Therefore, the estimation of each sensor node's location has been implemented by RSSI.

Fuzzy Logic (FL) is a multivalued logic which permits intermediate values to be defined between conventional evaluations such as yes or no, high or low, true or false, which has two different meanings. In the narrow sense fuzzy logic is a logic system of an extension of multivalued logic. FL has is different in both substance and concept of traditional multivalued systems in the narrow description. On the other hand, in a wide sense, FL is synonymous with the theory of fuzzy sets that relates to classes of objects with limitations [29].

The sugeno fuzzy inference is used to estimate the location of each sensor nodes. In fact all the RSSIs are fed to the fuzzy system to achieve the weights to be used in centroid relation in order to estimate the location of the sensor nodes.

1.4 Outline

The range free method has different techniques to estimate the position of sensor nodes in a specific region. In this thesis, Centroid localization has been utilized for implementation and experimentation. RSSI is achieved by estimating the distance between each anchor and the sensor node.

Estimating the location of each sensor node will be done by the centroid method. Hence, the weights are the main parameters in the centroid relation, which are the output of the fuzzy system. In fact, the sugeno fuzzy system is received RSSIs as inputs to map the outputs, which are weights of each anchor node to the sensor node.

Chapter 2

WIRELESS SENSOR NETWORKS

2.1 Principles of WSNs

Wireless Sensor Networks consist of unique nodes which are small, battery powered devices that can compute and communicate different signals in their environment. The WSNs have many applications in buildings, air traffic control, manufacturing automation, environment monitoring, industry and security [1].

Figure 2.1: Wireless Sensor Network

Wireless Sensor Networks are particularly attractive in risky environments, such as those which require a very large amount of ambient data with a large deployment environment. In WSN applications, one of the important problems is the locations of the unknown sensor nodes for the base service. The localization plays an important role where there is doubt about a sensor’s position. One of the applications of wireless sensor networks can be to monitor the temperature in a structure/place where the correct position of each node becomes very important. If, for example, the sensors are used for monitoring the temperature in a forest, nodes can be deployed from an airplane and the exact position of sensors will be unknown. As in this example indeed, one of the advantages of localization algorithm is to collect all the available information from the nodes to compute the unknown positions [2].

2.2 Specifications of WSNs

Figure 2.2 shows an example of a Wireless Sensor Network scenario in which a large number of nodes are randomly deployed in the vicinity of an inspected phenomenon.

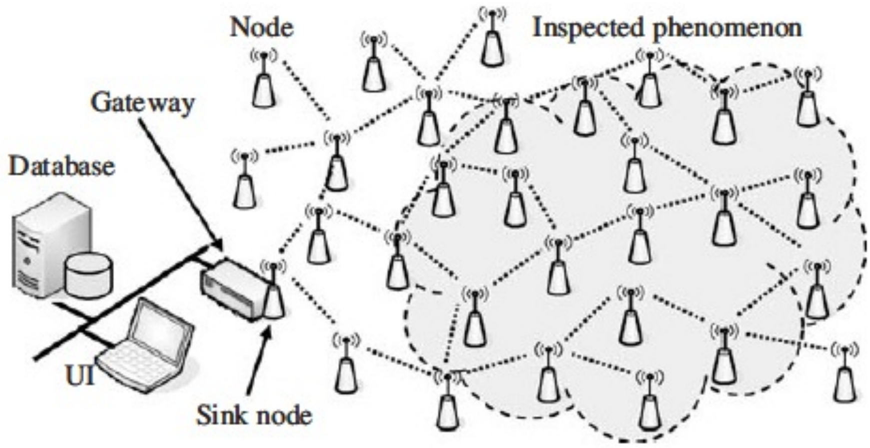

Figure 2.2: An example of a WSN Scenario [3]

The nodes are self-organized and communicate with others; the sensing process depends on the phenomenon. Instead of sending raw data, each node pre-processes its measurement outcomes. The outcomes are aggregated to reach high-level application results. The data will be forwarded to a data gathering point, which is called the sink node [3]. The sink node acts as a sample of gateway to the other networks and to human users.

2.2.1 Applications of Wireless Sensor Networks

The small size of the nodes, corrective maintenance and autonomous operation of WSNs allow them to be easily develoyed even in rough and dangerous environments.

The most common use of WSNs are in the field of measuring temperature, humidity, pressure, sound and location. The envisioned applications of WSNs are usually derived as a consequence of wider applications. The most typical domains for WSNs are home automation, environmental monitoring, security, traffic control, defense and industrial monitoring and control [4].

The data gathering and processing are the two important functions of WSNs. There are four main tasks which are independent of application domain [4]: (1) Monitoring. This task uses periodic measurements which determine the value of a parameter in the given position or coverage area of the Network. (2) Detection of the events. Detection is the occurrence of events of the main subject and their parameters. (3) Aim of classification. Generally this task requires the combination of data from various sources and a collaborative processing to find the result, identify the object or event. (4) Aim of tracking. Tracking the position and movements of a mobile object within the coverage area of the Network.

2.2.2 Requirements of WSNs

The generalization of the requirements is not feasible in detail when the deployed WSN depends on the application and environmental factors. Some of WSN applications that have general requirements for the node platforms, protocols and application can be defined [2] as given in subsections 2.2.2.1-2.2.2.6.

2.2.2.1 Fault Tolerance

WSNs must be robust enough about the exact locations of individual nodes against failures. The network's operation must be maintained and built in a dynamic nature against any failures of nodes which is the result of harsh environment, depletion of batteries and external interference.

2.2.2.2 Life time

The network life time is a serious problem in WSNs. The nodes are battery powered or the energy is scavenged from the environment and also their maintenance is hard. They are expected to be utterly functional for long time periods. Thus, load balancing and energy saving should be taken into account in the implementation of WSN platforms, applications and protocols [3].

2.2.2.3 Scalability

The numbers of nodes in a WSN are typically high. However, the scale partly depends on the covered zone, the replication of nodes, limited sensing coverage, and application requirements. Hence, the WSN protocols should be able to deal with the number of nodes and also high densities.

2.2.2.4 Security

The security in WSNs plays an important role especially in defense applications and health care. The security for WSNs is a tough way to fulfill because of the limited resources of nodes and time consuming algorithms [4].

2.2.2.5 Real time

WSNs have close relationships with the real world, so certain timing constraints for processing, sensing and communication exist. For instance, in the real time identification of a phenomenon the simulation of sensors should be captured first and then, the obtained data are processed after the phenomenon is identified. The result must be transferred instantly through the network.

2.2.2.6 Cost of production

As mentioned above, the number of nodes in wireless sensor networks is very large, and they may run out of batteries. Furthermore, the dead nodes are replaced with the new ones. Therefore, for low-cost deployments, the cost of a node must be kept very low.

2.3 Platform of WSNs

In every network, hardware implementatioin has significant effects on the energy consumption and the achieved performance of the network. The energy efficiency in WSNs is implemented by medium access control and networks layer of protocol which reduce the activity of hardware by less than one percent. The activity occurs at very short time periods. Clearly, the most important part of active operation mode is the low power usage. The main factor in WSNs is the minimization of power consumption in sleeps modes. The sleep mode or idle energy usage dominates a network's lifetime in very low data rate applications [5].

2.3.1 Platform Components

The large number of nodes required is the main reason for the hardware realization to be low-cost and small; however, the operating time must be stretched by using small batteries. The Application Specific Integrated Circuit (ASIC) is the best technique for fulfilling the given requirements for hardware realization. Energy-efficient computation is possible when the hardware is application specific and contain application-hardware accelerators [6]. The level of design and initial costs cause ASICs to be cost-effective just for very high production volumes. Figure 2.3 represents a WSN node as a general hardware design. There are four subsystems for architecture that can be divided into communication subsystem, which is for wireless communication, computing subsystem, which allows data processing and managing node functionality, sensing subsystem that can link the wireless sensor node to the outside and power subsystem to provide the system supply voltage [7].

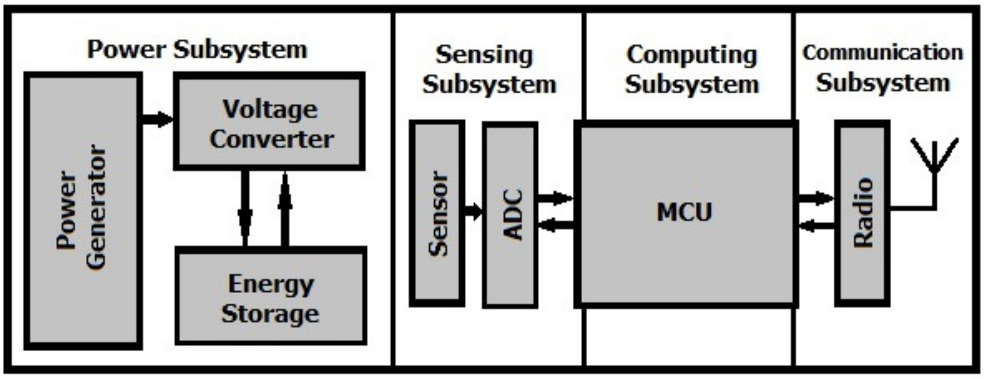

Figure 2.3: General hardware design of a WSN node [7]

The Microcontroller Unit (MCU) is the central part of the platform, which can form the computing subsystem. Furthermore, part of the communication and sensing subsystems are executed on the MCU which include device drivers and network protocols.

2.4 Design of WSNs

A comprehensive of all-purpose WSN, which fulfills the requirements of all possible applications, is not a sensible aim. The diversity of applications may cause conflict in objectives which cannot be met with one design. Therefore, all the devices of a deployed WSN must be choosen depending on the application requirements. One of the options is the design and implementation of a new WSN totally from scratch. The WSN design space results in new nodes platforms, protocols and applications. Furthermore the protocols can be configured to other operation modes. Indeed, in the future WSNs design space will become so big that designers will not be able to balance it without suitable support devices [8].

2.4.1 Dimensions of Design

The design dimensions represented here are partly overlap with the main requirements. For instance, a long life time is one of the main requirements which WSNs are expected to have to be functional [9]. The dimensions are selected with respect to two major factors: firstly, the significance of the application and secondly, the effect of the selected design.

2.4.1.1 Deployment

The deployment process could be made randomly or nodes could be manually set to designated places. In addition, the distribution of nodes can be at single times or iterative, in which case the battery or node replacements are continuous.

2.4.1.2 Mobility

WSNs can be classified as immobile or partly or fully mobile which is related to the ratios of moving nodes. Hence, there is a difference between fully and partly mobile which means that partly is only a subset of nodes moving, however, in the fully mobile all nodes are moving. Mobile nodes can be moving objects by the influence of nature such as wind, earthquake, and landside. Indeed, the mobility in nodes can be active or passive which depends on the node's mobility.

2.4.1.3 Cost, Size and Energy

The size of each node can be described from large to small. The energy can be collected in batteries from the environment or the nodes can be mains powered. The cost of each node depending on many factors such as size and resources can vary from a few to hundreds of dollars [8].

2.4.1.4 Communication in WSNs

The communication in WSNs is based on electromagnetic waves. There are many transmission band options depending on the location and application. There are also some different communication modalities such as light beams, capacitive coupling and inductive coupling that can be used in the network.

2.4.1.5 Sensing Coverage

There is a difference between sensing and radio coverage, which means that in the radio communication, the coverage is significantly wider than the sensing coverage. In the applications, sensing coverage is referred to the support to an event that has to be detected. Therefore, the sensing coverage is an important role from the application point of view. The coverage of a network is categorized in three different methods as spare, that only parts of the zone of interest are covered, dense if the complete system is covered and redundant coverage when multiple sensor nodes receive the same data in the same area.

2.4.1.6 Connectivity of WSNs

The radio coverage plays a significant factor in the connectivity of WSNs. When two nodes are connected, there exists a continuous multi hop connection. The size of the network depends on connectivity, coverage, the size of the zone of interest and the number of the deployed nodes.

2.4.1.7 QoS requirements

The application and target environment that have been set are the quality of service requirements to WSNs, which must be considered in the WSN design; they also have an effect on the dimensions. Some examples of possible application of QoS requirements are robustness, tamper resistance, information security and real time constraints [9].

2.5 Protection in WSNs

Protection among nodes for the data transfer is an important part of the WSN application. Impermissible parties shouldn't be able to access private information that may be collected by WSNs. WSNs are significantly more prone to interference in comparison with other wireless networks like WLANs [10].

2.5.1 Threats in a WSN Security

The definition of security is a state of defense against intentional acts of smart dangers which implicates a failure to cover safety to some extent and that safety is defined as a defense in front of random events such as any failures. Security is designed to involve a selection of ways for providing security such as protocols, algorithms and their application. The attempt to breach a security system is considered as a security attack. On the other hand, a security threat of alternative communication networks may include message interception, fabrication and modification [11]. The threats are inherent in WSNs which affect their wireless operational environments and introduce special limitations in their operations. The WSNs have limited capabilities against attackers who may possess powerful devices like laptops.

2.5.1.1 Passive Attacks

Passive attacks present in the form of interception of messages sent by the system [11]. In traffic analysis, the attacker finds out beneficial information through message header, sizes, transmission frequencies, etc. However, the attacker may not be able to understand the exact message content. In WSNs, gathering details exchanged between nodes are called interception attacks.

2.5.1.2 Active Attacks

The active attacks on WSNs consist of modification and fabrication of details in several different forms. Fabrication has two samples which are impersonation and response to a message. On the other hand, modification consists of changing, deleting, reordering message and data. Furthermore, WSNs are vulnerable to node capturing and tampered routing attack in performing active attacks [12].

Chapter 3

Localization in Wireless Sensor Networks

3.1 Introduction to Localization in WSNs

Recently, wireless sensor networks are used in different environments to obtain various tasks such as search, disaster relief, target tracking and also a number of duties in smart environments. Node localization is needed to report in different situations such as the origin of events, assist group querying of sensors and also to answer the questions on the network coverage. Hence, node localization has become one of the fundamental challenges in wireless sensor networks [13].

The significant advances in micro-electro-mechanical systems (MEMS), communication technology and computing have motivated initiation of a large number of increasing applications of massive distributed wireless sensor networks which consist of hundreds or thousands of nodes. Every node is expected and able to sense the environment, compute and communicate with a central unit or other sensors in the system. The network topology is made up of randomly distributed nodes in a region, which is a common way to deploy wireless sensor networks. The network is referred to as an ad-hoc network since there is no established priori communication protocol [14]. Establishing a design efficient localization algorithm depends on a successful localization scheme in order to compute the correct position in a coordinate system. For example, in a kindergarten node localization can be used to monitor the interaction of children with toys.

Unfortunately, when the number of sensor nodes is increased, adding GPS connection to all nodes in the network is not an entirely feasible method because :

- GPS method can not be implemented in a dense forest, mountainious terrain or other places with blocked line of sight communications with the GPSs.
- The power consumption of GPS system decreases the battery life of the sensor nodes which causes a reduction in the life time of the entire network.
- The cost of production of a GPS network is an important problem with a large number of nodes.
- The size of GPS coverage and the antenna cause a significant increase in the size of the sensor nodes by a considerable factor, however, the area/size of the sensor nodes should be small [15].

There are two kinds of nodes in WSNs which are anchor nodes and unknown sensor nodes. Some sensor nodes are aware about their positions which are called anchors or beacons. Anchor nodes contain energy and accurate information about their position. However, unknown sensor nodes don’t have those specifications. One of the most significant problems in WSNs is the localization of the unidentified sensor nodes for the location based on service and plays an important role for different application scenarios in WSNs [16]. The localization methods usually have three phase models as summarized below:

- Calculating the distance between the anchor nodes and unknown sensor nodes.
- Node distance position from its anchor distance.

- The estimated node location by using the information from the range or distance of the neighbouring nodes.

For the first phase, each node first uses communication capability to achieve some measurements like time of arrival to their neighbors for estimating the single hop distance after that using methods like distributed shortest path distance algorithms to estimate multi hop distance of the beacon nodes [17].

For the second part, each node uses methods such as triangulation to calculate its position by using distances of three or more beacon nodes. In the last part, each sensor node finds position according to the constraints on the distances to its neighbors.

Therefore, there have been some research about localization in WSNs which can be divided into two classes: range based and range free schemes which are different in the information used for localization. Range based schemes are more accurate which have important roles in applications such as target tracking and localization. On the other hand, using the range free scheme can be simplified due to hardware design where only the anchor nodes need to have knowledge about their locations [18].

3.2 Range Based

The range based schemes required either node to node distance or the angles for estimating positions. However, in the range free schemes just the content of each message is used. Hence location of nodes in that method are computed respective to the other nodes which are located in their neighbors. Range based methods calculate the exact distance from transmitting to receiving sensors. Thus, the range based schemes contain various techniques to first compute the distance between nodes or range to the number of their vicinity and after that to compute the position by using geometric principles.

Therefore, they need more sophisticated hardware to estimate the range such as time of arrival (TOA), time different of arrival (TDOA), angle of arrival (AOA) and received signal strength indicator (RSSI). The range-based schemes have higher location accuracy in comparison with the range free schemes where localization can estimate the absolute point to point distance based on RSSI or other techniques of the received communication signal. On the other hand, the range based approach has some disadvantages such as it requires additional hardware to estimate the distance or angles and has problems in the noisy environments [19].

3.2.1 Time Based Techniques (TOA, TDOA)

The time of arrival (TOA) and time difference of arrival (TDOA) are time based techniques which convert the propagation of time into distance. The propagation of time is converted into distance based on the known signal speed. These techniques can be used with many kinds of signals such as RF, acoustic and infrared. TDOA technique is accurate when there is line of sight conditions but the line of sight conditions are difficult to meet in some environments [20].

In the time of arrival, the distance between a reference point and receiver node is estimated by the time of flight of the communication signal. In this technique, all the sensors transmit a signal to other nodes which are located in their neighborhoods with a predefined velocity V that is the same for all the sensors. After that, the receiving sensors send back a signal to the transmitting node. The distance between them is estimated by using the following equation [19]:

$$d_{ij} = 2^{-\frac{1}{2}}[(T^{i}_{rec} - T^{i}_{tra}) - (T^{j}_{rec} - T^{j}_{tra})] \quad (3.1)$$

Where the node i is neighbors of j, $T^{i}{}_{rec}$ and $T^{i}{}_{tra}$ are the time of transmission for the signal at node i respectively and $T^{j}{}_{rec}$ and $T^{j}{}_{tra}$ are also the time of transmission of signal accordingly for node j [19].

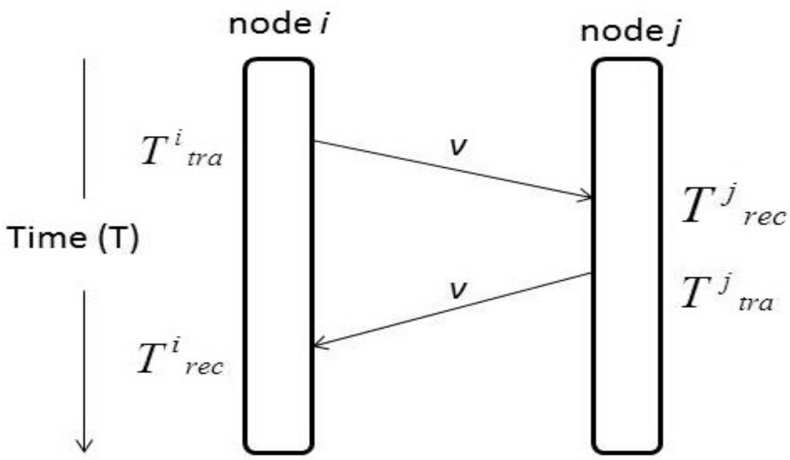

Figure 3.1: Time of arrival Method

After estimating the distance the method of trilateration is used for finding the position of the sensor.

3.2.2 Angle of arrival (AOA)

Angle of arrival method estimates the angle of signals which are received and use simple geometric relationships to estimate the node location. The angle of arrival (AOA) method is related to direction of arrival (DOA) which can be estimated by the relative or absolute angles between the neighbors. Angle of arrival is defined as the angle between some reference direction and propagation direction of a random wave, which is known as orientation. The orientation can be defined as a fixed direction against where the AOAs are estimated. The orientation is represented in degrees in a clockwise direction from the north [20]. The AOA becomes absolute when the orientation is 0^0 or pointing to the North.

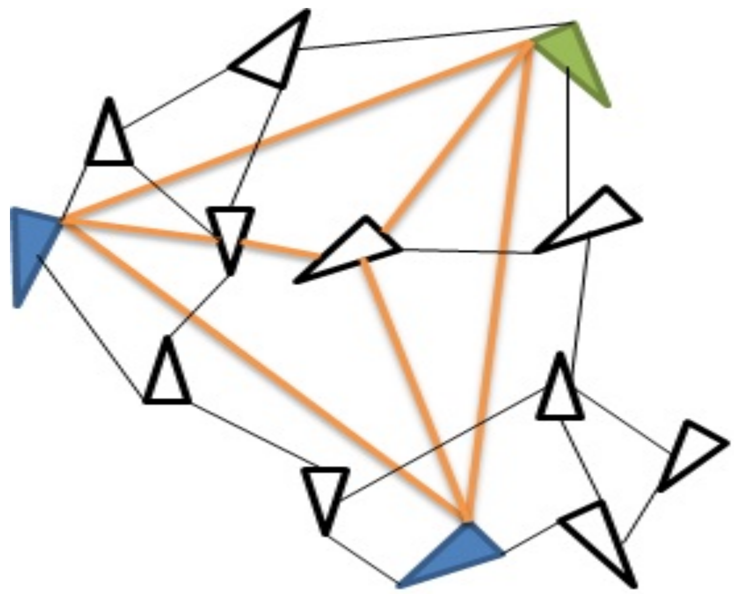

Figure 3.2: Angle of Arrival

In fact, AOA technique is more accurate in localization when compared to RSSI based method but the hardware in AOA is very expensive.

3.2.3 Received Signal Strength Indicator (RSSI)

Another technique to estimate the distance between neighboring sensor nodes uses the received signal strength measurements. The received signal strength indicator (RSSI) is based on a standard feature in most wireless devices. Generally RSSI estimates the power of the signal at the receiver which is based on the known transmitted power. Thus the effective propagation losses can be calculated. Hence, losses can be translated into an estimated distance by applying theoretical models. The energy of the radio signal is considered similarly to an electromagnetic wave which decreases as it propagates in space. The signal strength decreases as the wave propagates in space. Decreasing in signal strength is inversely proportional to the square of the distance travelled by the wave which is given as follows [21]:

$$\text{Signal Strength} \propto \frac{1}{d^2} \tag{3.2}$$

RSSI is attractive in comparison with other methods because they need no extra hardware and are unlikely to significantly impact on the local power usage, sensor size and cost. However, the accuracy of this method is not as good as other techniques because of the multipath distribution of radio signals [21].

3.3 Range Free

The simple design of hardware makes the range free methods very appealing and advantageous for localization in wireless sensor networks. On the other hand, the result in range free schemes are not as precise as the range based. However, its low cost and simplicity in estimating distances have increased the popularity of this method in the recent years. There are several range free localization techniques such as approximate point in triangle (APIT), multi hop, DV-Hop and centroid localization [22].

In the range free algorithms it is assumed that a few sensor nodes have their exact locations which are called the anchor nodes. The position of anchor nodes is used as a reference for estimating the unknown sensors location. The centroid technique is simple and communication overhead is low, thus the energy usage is relatively low. In contrast, DV-Hop is complex and cost of communication is high, but has a better localization accuracy. In fact, some factors such as localization accuracy, energy usage and computational complexity are considered when evaluating any localization algorithm.

3.3.1 Approximate Point in Triangle (APIT)

APIT is a region based range free localization scheme which assumes that a number of anchor nodes are equipped with high powered transmitters and their positions are known. APIT is located in an area to perform position estimation by isolating the area into triangular zones between anchor nodes as shown in Figure 3.3 [23].

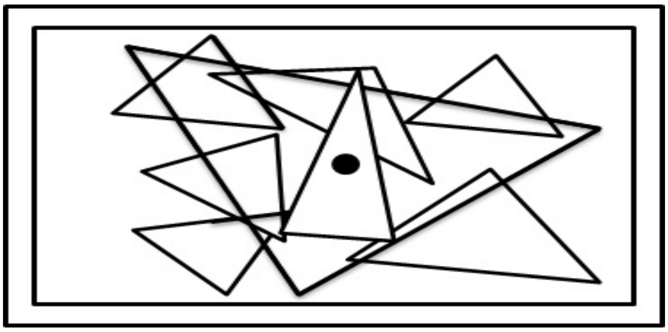

Figure 3.3: Area Based APIT Algorithm

Each node's presence inside or outside the triangular regions allows decreasing the feasible location until all the possible sets have reached to an acceptable accuracy. The point in triangulation test (PIT) is a theoretical technique which is used to narrow down the feasible area that a target node resides.

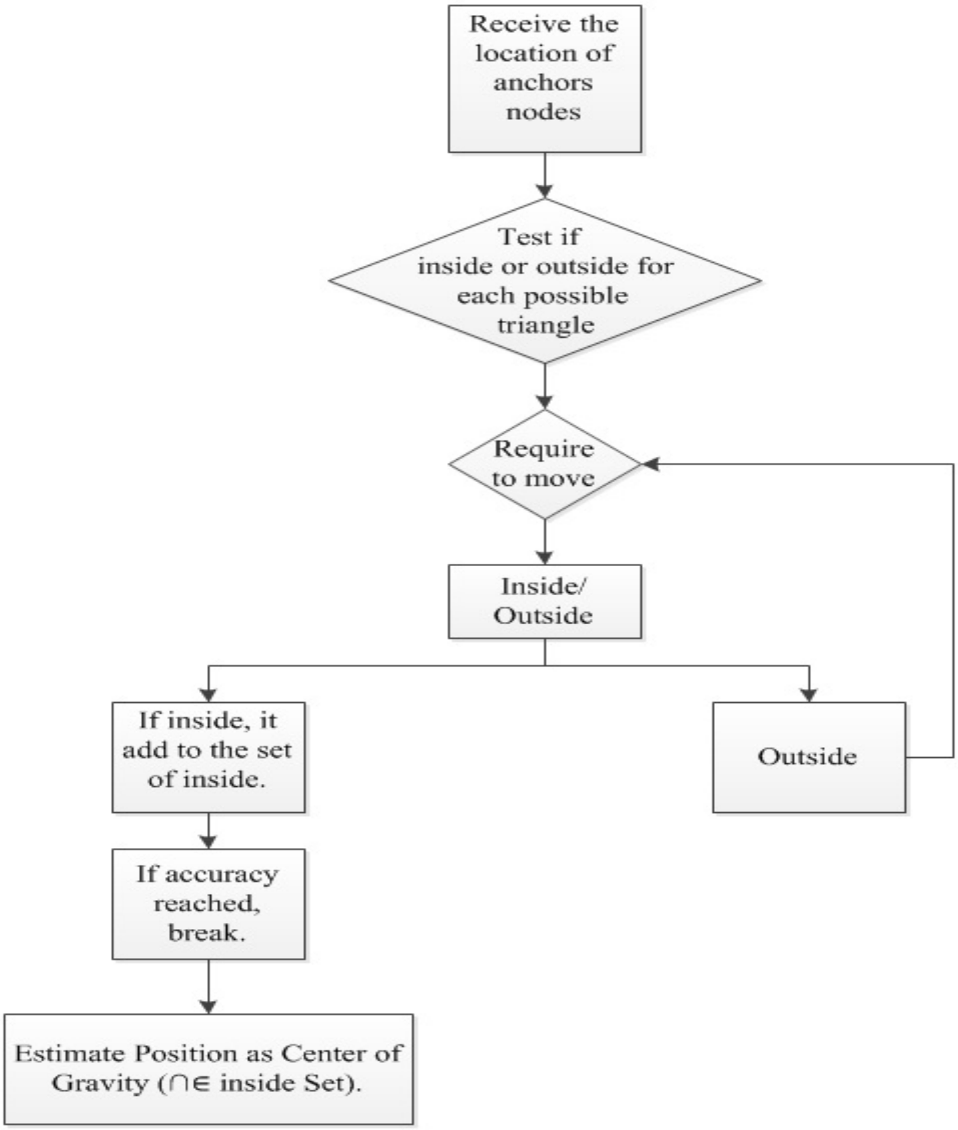

Figure 3.4: APIT Algorithms

According to PIT test, if the node is not inside a triangle, it requires moving. However, in some situation where nodes are unable to move APIT definition is changed [23].

The APIT technique uses Signal Strength which is not an estimate for a distance. It just assumes that signal strength decreases steadily with the distance.

3.3.2 Multi hop

Multi hop techniques are basically range free, while they can also be used to estimate the distance. They can compute a connective graph after trying to make it as a known location.

The multi-dimensional scaling (MDS) only uses connectivity information where the nodes are inside the communication range. This approach has three steps as follows [24]:

- Estimation of distance between each feasible pair of nodes.
- MDS driving locations to fit the estimated distance.
- Optimizing by putting the known positions into account.
- This system is designed by a connectivity graph. In a large sensor network, there are many kinds of MDS methods used such as metric or nonmetric, classical and weighted.

The multi-hop multilateration technique allow nodes which are many hops far from beacons to collaborate in finding better location estimates. Therefore, by using this type of collaboration, the proportion of beacons to the nodes can be reduced [24].

3.3.3 DV-Hop

In the DV-Hop localization technique a mechanism which is similar to classical distance vector routing is used. One anchor node in DV-Hop algorithm broadcasts a message throughout the network region which includes the anchors' positions with hop count parameter. Each receiving node keeps the minimum value per anchor, which it receives, and then ignores the other beacons with higher hop count values. Messages broadcasted out with hop count values incremented at every middle hop. In this mechanism, all nodes in the network region and other anchors get the shortest distance in hops. The overall single hop distance in anchor *i* is estimated with the following equation [22]:

$$Hop\ Size\ i = \frac{\sum \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum h_j} \tag{3.3}$$

Where the location of anchor *j* is (x_j, y_j) and h_j is the distance in hops from *j* to *i*. Anchors propagate the estimated hop size to the closest nodes. The unknown nodes can estimate their positions through triangulation algorithm. In this algorithm at least three anchor's location are used, which is shown in Figure 3-5.

The black nodes in this figure represent anchors nodes, U and white nodes indicate the sensor node positions which are unknown and calculated by DV-Hop technique [22].

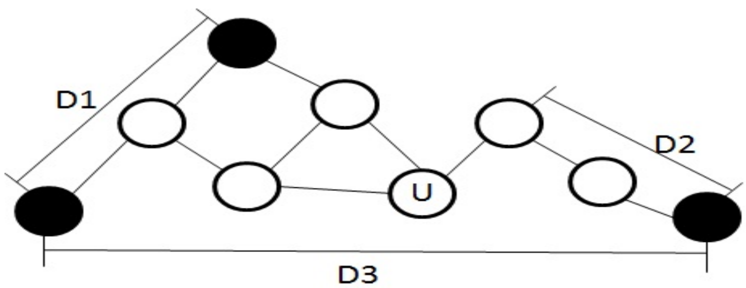

Figure 3.5: DV-Hop Algorithms through triangulation

The increase in anchors causes increased errors in exact localization with the distance [25].

3.3.4 Centralized Localization

The WSN localization methods used to estimate the unknown positions of each sensor with the available prior knowledge of position sensors in the network which are used as reference for the others. The reference nodes are sensors with known locations which were installed at points with known coordinates. However, the other sensor nodes do not know their locations. These sensors with unknown location information are unknown nodes, so their coordinates require reference sensor algorithms to estimate their positions. Range free methods do not depend on the distance. Therefore, in this method, hardware design is simplified so that only the reference nodes have information about their own locations [23].

In centroid algorithms, the location of unknown nodes are estimated by the coordinates of their neighbor's reference nodes. In fact, centralized localization is mainly based on transferring of inter node ranging and connectivity data to an adequately powered central base station.

The benefit of centralized localization method is that it omits the problem of computation in every node and also the limitations stand in the communication cost of moving data coming back to the base station at the same time. The centroid localization scheme is simple and easy to implement. In simple centroid localization algorithm, it is needed to calculate a node's location based on the position of many reference nodes which is simple but the estimated error might be high because of the simple nature of the centroid formula. Using weighted reference nodes minimizes this problem of localization errors [26].

3.3.3.1 Fundamental Centroid

The range free algorithm, based on proximity, uses the location of anchor nodes (reference nodes) (x_i, y_i) to estimate the nearest unknown node [26]. The task of the centroid algorithm is to take several nodes around the unknown nodes as polygon vertices and the unknown node as the centroid of polygon which is indicated in Figure 3.6.

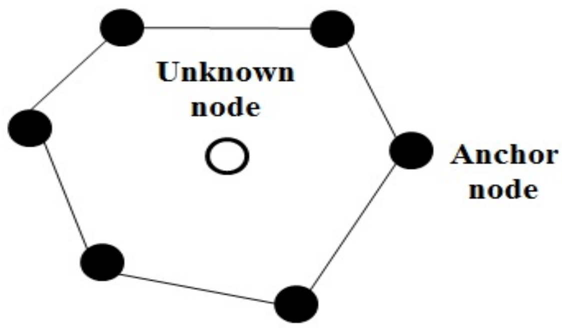

Figure 3.6: Centroid Localization Algorithms

After receiving the message, there is a relation for estimating the coordinates of the unknown node as follows:

$$(X_{est}, Y_{est}) = (\frac{X_1 + ... + X_N}{N}, \frac{Y_1 + ... + Y_N}{N}) \quad (3.4)$$

Where (X_{est}, Y_{est}) indicates the estimated position of the sensor node and N is the number of the anchor nodes which is connected to sensor node. This algorithm result is simple but is not sufficient for estimating position, hence the implementation of weighted reference nodes is required to solve the problem.

There is a method to improve the previous technique where anchor nodes are weighted in terms of their proximity to the sensor nodes. Hence, each sensor node computes the location by this formula [18]:

$$(X_{est}, Y_{est}) = (\frac{x_1 w_1 + ... + x_n w_n}{\sum_{i=1}^{n} w_i}, \frac{y_1 w_1 + ... + y_n w_n}{\sum_{i=1}^{n} w_i}) \quad (3.5)$$

This method has a weakness due to the choice of the weights $(w_1, w_2, ..., w_n)$ and the performance depends on the choice of the weights.

3.4 Soft Computing

Soft computing is an important role to solve technological problems and it is appropriate for uncertain and nonlinear formulations. In fact, soft computing attempts to achieve tractability, robustness and low solution cost. Soft computing technique in fuzzy logic plays a crucial role in this thesis [18].

Chapter 4

Fuzzy Logic

4.1 Description of Fuzzy Logic

Lotfi Zadeh introduced the mathematics of fuzzy logic theory in 1965 [27]. Fuzzy logic supplies the opportunity to model conditions which are inherently incorrect descriptions.

Fuzzy Logic (FL) is a multivalued logic which permits intermediate values to be defined between conventional evaluations such as yes or no, high or low, true or false, which has two different meanings. In the narrow sense fuzzy logic is a logic system of an extension of multivalued logic. FL has difference in both substance and concept of traditional multivalued systems in the narrow description. On the other hand, in a wide sense FL is synonymous with the theory of fuzzy sets that theory relates to classes of objects with limitations [27].

Fuzzy logic claims to have the ability to use human mind as operative modes of reasons which are more than exact. In the common hard computing, certainty and precision have added cost. The principle of soft computing can be defined as to exploit the tolerance for preciseness, uncertainty and partial truth to obtain robustness, low cost solution and tractability [27].

The fuzzy logic provides a distinct way to achieve a control or classification problem. This method has focused on what the system must do rather than trying to model how it works and also it can concentrate on solving a problem more than the mathematical modeling of the system. The fuzzy logic is an area of research which is a fascinating trade-off between significance and exactness. Fuzzy logic is a reasonable way to map an input space to an output space where mapping is the starting point for a design [28].

In fact, one of the concepts in fuzzy logic is if-then rules which are used in artificial intelligence to deal with fuzzy definitions. Indeed, a fuzzy logic solution is an interpretation of a man-made result. On the other hand, FL can model nonlinear functions of optional complexity to a sufficient degree of exactness. Fuzzy logic is a simple way to model a multi-input multi-output (MIMO) system [29].

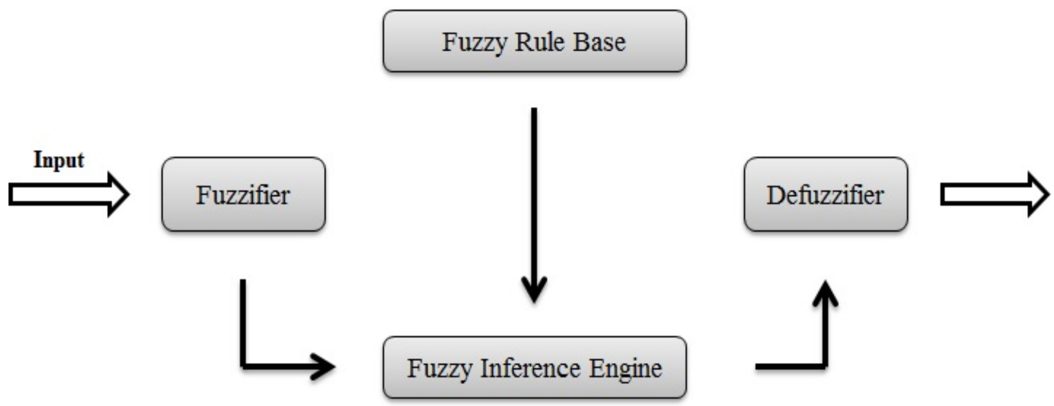

Figure 4.1: The Fuzzy Logic System.

Totally, the fuzzy logic system is an inference system which includes a fuzzifier, some if-then rules, defuzzifier and fuzzy inference engine as shown in Figure 4.1 [29].

4.2 Advantages of using Fuzzy Logic

Lotfi Zadeh, remarked that in almost every case we can build the same product without fuzzy logic, but fuzzy is faster and cheaper. There is a list of advantages of using fuzzy logic [30]:

- Fuzzy logic is easy to understand when the mathematical concepts in fuzzy are very simple. FL without the variety of complexity is a more intuitive approach.
- Fuzzy logic is flexible with any given system.
- Fuzzy system can be matched to any set of input-output data. Hence fuzzy logic tries to model nonlinear functions of arbitrary complexity.
- Fuzzy logic can be mixed with conventional control techniques.
- Fuzzy logic is easy to use because it is built on a structural description used in any language. Natural language is the most important advantage of fuzzy logic. It is used by ordinary people daily that sentences written in an ordinary language indicate an achievement of efficient communication.

On the other hand, fuzzy logic is not a cure for all, hence in some situations using fuzzy logic is not a useful way. As it is mentioned before, fuzzy logic is a convenient way to map input to output and if not possible we should try other methods [30]. However, if a simple solution already exists, we use it. Indeed fuzzy logic is the codification of common sense.

4.3 Fuzzy values, Fuzzy sets and Rules

All values with one interpretation are called crisp values which are clearly defined and measurable. They are also called singleton values which are opposed to a set of values that can be defined as fuzzy values. In contrast, fuzzy values are unclear and have many different interpretations, and also different values may be associated with them [31].

A Fuzzy set is defined as the ability to use fuzzy values in control settings where a set of values are related to a fuzzy value which can be members of this fuzzy set. The consideration of description of a classical set is an important way to understand what a fuzzy set is. A classical set is defined as a container which totally includes or excludes any given element. Generally, the membership function is defined as a curve which includes each point in the input mapped to a degree of membership between 0 and 1. In the fuzzy set, each value has a degree of membership within the set from 1 membership (100%) to 0 memberships (0%). Therefore, in crisp value, there is a unique correct value and other values which are relative are incorrect. The fuzzy set has fuzzy values where each value has a degree of accuracy and varies from 100% true to 0% true [31].

The primary mechanism to map an input space to an output space of the point of fuzzy logic is a list of if-then statements which are called rules. All rules are evaluated in parallel because they refer to variables and the order of the rules is not important.

4.3.1 Connection with Logical Operations

The superset of standard Boolean logic is the most important tool to understand fuzzy logic reasoning. In fact, if we hold the fuzzy values at their extremes of totally true or totally false, the logical operations remain. Where x and y are bounded in the range *(0,1)*, the min operation is *x AND y*. The same explanation using the *OR* operation resolves max operation, thus *x OR y* is equivalent to max *(x,y)*. The other operation is *NOT x* which is equivalent to the operation *1-x*. Generally, *AND* is the fuzzy intersection or conjunction, *OR* is the fuzzy union or disjunction and *NOT* is the fuzzy complement. Obviously, most fuzzy logic applications use these functions which are arbitrary [29].

4.3.2 If-Then in Fuzzy Logic

Fuzzy sets and fuzzy operators are two parts of the subjects of fuzzy logic. To formulate the conditional statements we use if-then rule statement:

$$\textit{If } x \textit{ is } A \textit{ then } y \textit{ is } B \tag{4.1}$$

This formula is assumed as a single fuzzy if-then rule statement where *A* and *B* are values on the range of *X* and *Y*. The former part of the statement where "*x is A*" is called premise or antecedent. However, the latter part of the statement where "*y is B*" is called consequence or conclusion [28].

If-then rules have three steps to process as follows:

1. Fuzzify inputs which are decomposed all fuzzy statements in the antecedent into a degree of membership where if there is just one part to the antecedent then it is a degree to support the rule.

2. Using fuzzy operators to multiply antecedents: if there are multiple parts to the antecedent, apply fuzzy logic operator to decompose antecedent to a single number.

3. Applying implication technique where the degree of support for the rule is to create the output fuzzy set. This fuzzy set is indicated by a membership function which is chosen to represent the qualities of the conclusion.

In fact, just one rule is not operative and also the output of every rule is a fuzzy set [28].

4.4 Fuzzification and Defuzzification

The process for converting input values to output values into their membership functions is called fuzzification which is the result that indicates degree of membership in different sets of fuzzy variables. The story about defuzzication is different. In fact, one rule alone is not impressive; hence two or more rules are needed. The fuzzy set is the output of each rule where the output fuzzy set for each rule is aggregated into a single output fuzzy set. Defuzzification has a task to resolve a single number in the resulting set. The center of gravity method and Mamdani's inference method are two possible techniques for defuzzification [32].

4.4.3 Center of Gravity

The membership value for each output variable in this method is obtained by multiplying the maximum singleton value of the output membership set to get an equivalent value for the output of the membership set in question. After that the normalized membership value is an equivalent output value for the output. These are summarized in two steps [33]:

- Multiply the membership degree for the output by the singleton value of the output.
- Sum all the preceding values together and divide by the sum of membership degree of the output.

4.4.2 Mamdani's Inference

The membership function of each set is cut at the corresponding membership. The resulting membership functions are added together as an "or" function. Mamdani's method has three steps as follows [33]:

- Truncate each membership function of output at its corresponding membership value, which is based on the rule.
- Sum the remaining truncated membership functions with an "or" operator in order to stabilize into area of the output.

Calculate the center of gravity of the stabilized area as the crisp output value.

In the defuzzification, most programs integrate the area under the curve; however, hand calculation can be achieved with any technique [34].

4.5 Fuzzy Inference Rule

The process of formulating the mapping of a given input to an output by using fuzzy logic is called fuzzy inference. The controller part of the system has the task of fuzzy inference rule which is based on the truth table logic. Hence, the rule base has an important role due to a collection of rules which are related to the fuzzy sets, the input variables and output variables. The rule base is meant to permit the system to decide what to do in each case. Depending on the number of inputs and outputs, the rules take one of the following forms [35]:

If <condition> then <consequence>

If <condition1 and (or) condition 2> then <consequence>

If <condition1 and (or) condition 2> then < consequence 1 and (or) consequence 2>

In fact the fuzzy inference is a technique which interprets the values in the input to send to the output based on some set of rules.

The process of fuzzy inference is described as using inputs, rules and one output as shown in Figure 4.2 [35].

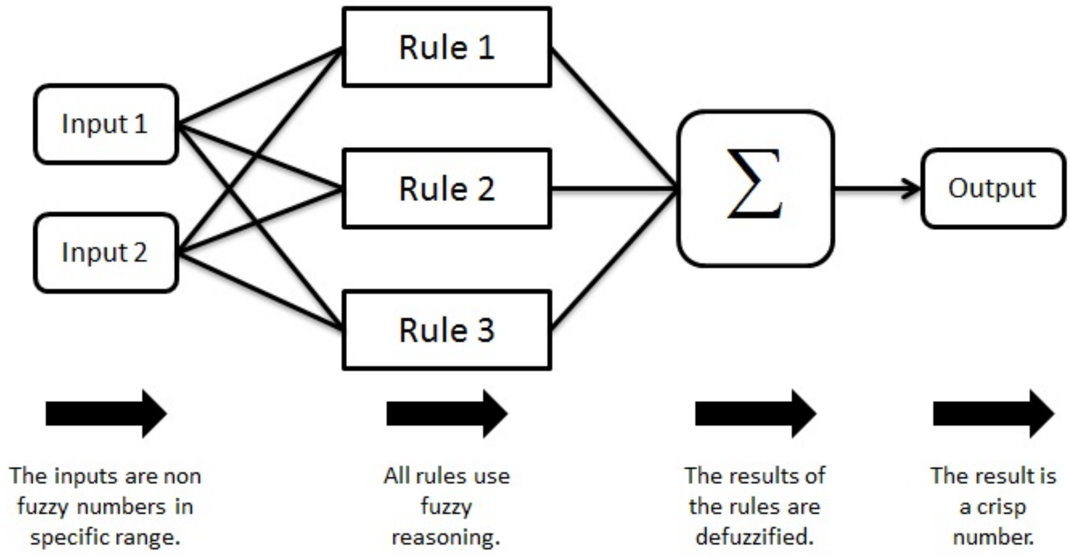

Figure 4.2: The Fuzzy Inference Process.

The information from left to right in Figure 4.2 represent convergence from two inputs to a single output. The parallel nature of rules is an important property of fuzzy logic methods.

There are five step to process the fuzzy inference such as fuzzification of the input values, using the fuzzy operator like AND or OR in antecedent, implication from condition to consequent, aggregation of consequences and in the last part defuzzification [36].

4.5.1 Fuzzification of inputs

The main aim in the first step is to take the inputs and assign the degree by membership functions to which they belong to each of the fuzzy sets. In the input, always a crisp value is limited in the interval between 0 and 1 and also this limitation is the same for the fuzzy degree of membership in the output. The fuzzified inputs are either a lookup table or a function evaluation [36].

4.5.2 Applying Operators

In the second part, when the inputs are fuzzified, the degree of each part of condition is satisfied for each rule. Hence, if the condition of a given rule has more than one part, the result of the condition for that rule will be applied by the fuzzy operator to achieve one number which this number applied to the output function. The input to the fuzzy operator is two or more membership values of fuzzified input variables, however, the output is a single truth value [37].

4.5.3 Applying Implication

Each rule has a weight which is a number between 0 and 1 to apply to the number given by the antecedent. When weight is 1, it has no effect on the implication method. Thus the weight of one rule is related to the others by changing its weight value to something except 1. Assigning the rule’s weight is done before applying the implication method. A consequence is a fuzzy set as membership function, which is changed to use a function associated with a single number. Therefore, the input in the implication method is a single number given by the condition and the output is a fuzzy set. Implication is implemented for every rule [37].

4.5.4 Aggregation

The rules in a fuzzy inference system must combine in some way in order to make a decision because decisions in FIS are based on the testing of all the rules. So aggregation is the process by the fuzzy sets that indicates the outputs of every rule mixed into a single fuzzy set. Aggregation occurs just for each output variable before the last step which is defuzzification. In the aggregation step, the input is the list of truncated output functions returned by the implication method for every rule. Thus the output in the aggregation process is a fuzzy set for each output variable [38].

4.5.5 Defuzzification

In the defuzzification process, the input is one fuzzy set which is the output fuzzy set in the aggregation and also the output is a single number. The fuzzification process helps for rule evaluation in the preview steps of aggregation. Generally, the last step is desired to be a single output number. However, the aggregation of a fuzzy set includes a range of output values which must be defuzzified in order to resolve a single value of output from the set. The centroid calculation is the most popular defuzzification method which is related to the center of the area under the curve [38].

Chapter 5

Implementation and Experimentation

5.1 Overview

This chapter is about the implementation and experimentation of the localization of a WSN by using the sugeno fuzzy method. The localization has two different techniques, range free and range based. The range free method is considered in the implementation because of the lowest cost and the highest accuracy compared to the range based. In fact the range based technique needs specific hardware to estimate the distance and TOA, however, the range free is done without any complicated hardware.

The range free method has different techniques to estimate the position of the sensor nodes in the specific region. Using RSSI, which is one of the techniques of range free considered in the both, implementation and experimentation is done. RSSI is achieved by estimating the distance of each anchor to the sensor node.

Estimating the location of each sensor node is done by the centroid method. Hence, the weights are the main variable in the centroid relation, which are the outputs of the fuzzy system in the simulation. In fact, the sugeno fuzzy system is received RSSIs as inputs to map the outputs, which are weights of each anchor node to the sensor node.

In this thesis both analytical and experimental methods are performed to achieve the location of the sensor nodes with minimum error.

5.2 Implementation

As considered in the previous chapters, a WSN consists of sets of anchor nodes and sensor nodes that anchor nodes are located at known position as $[(X_1,Y_1),(X_2,Y_2),\ldots,(X_N,Y_N)]$ and transmit signals with a known strength. Figure 5.1 shows the flowchart which gives the step by step implementation.

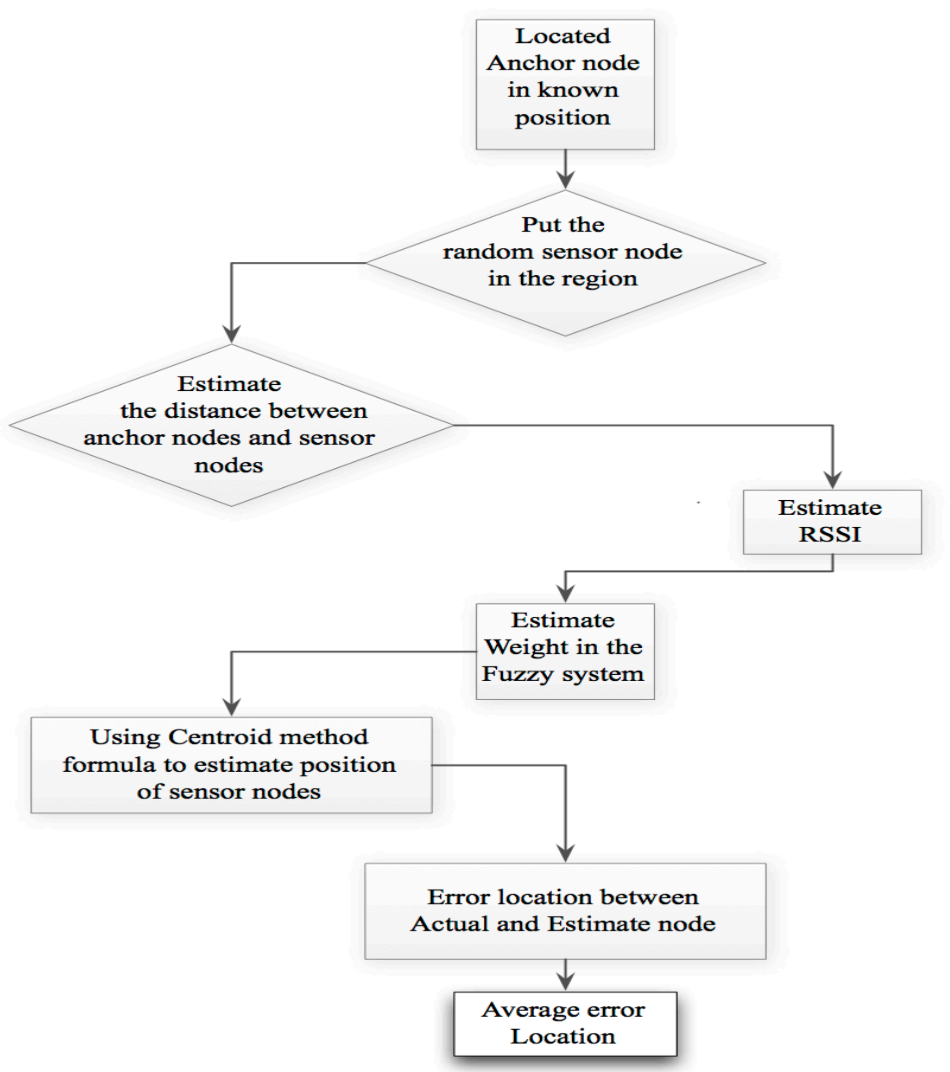

Figure 5.1: Flowchart of the Implementation

The anchor nodes in this implementation are located at (0,0), (10,0), (10,10) and (0,10). The sensor nodes are distributed randomly in the specific region and receive signal strengths from the anchor nodes to estimate their location. The main responsibility of a sensor node is collecting the RSS information which is sent by the anchor nodes.

This implementation has been done by sugeno type fuzzy inference method. The sugeno fuzzy inference is similar to the Mamdani method, however, the main difference between those methods is that the membership functions of output in the sugeno method is constant or linear. Figure 5.2 shows the sugeno fuzzy inference that is used.

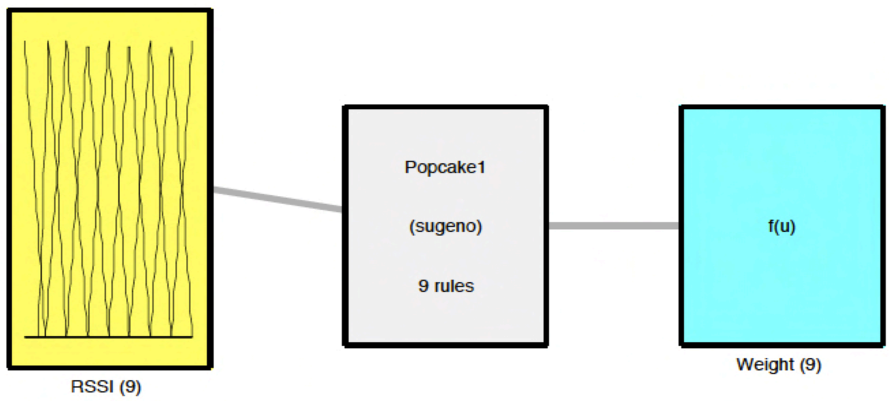

Figure 5.2: Sugeno Fuzzy Inference (1 Input 1 Output 9 Rules)

In this implementation, the input membership function of the sugeno method is the RSS from anchor nodes, which are decomposed into nine triangle membership functions such as very very low (VVL), very low (VL), low (L), medium low (ML), medium (M), medium high (MH), high (H), very high (VH), very very high (VVH) as shown in Figure 5.3. The input membership functions take value $[RSS_{min}, RSS_{max}]$ where RSS_{min} and RSS_{max} are the minimum and maximum RSS respectively, which are received by each sensor from each anchor node.

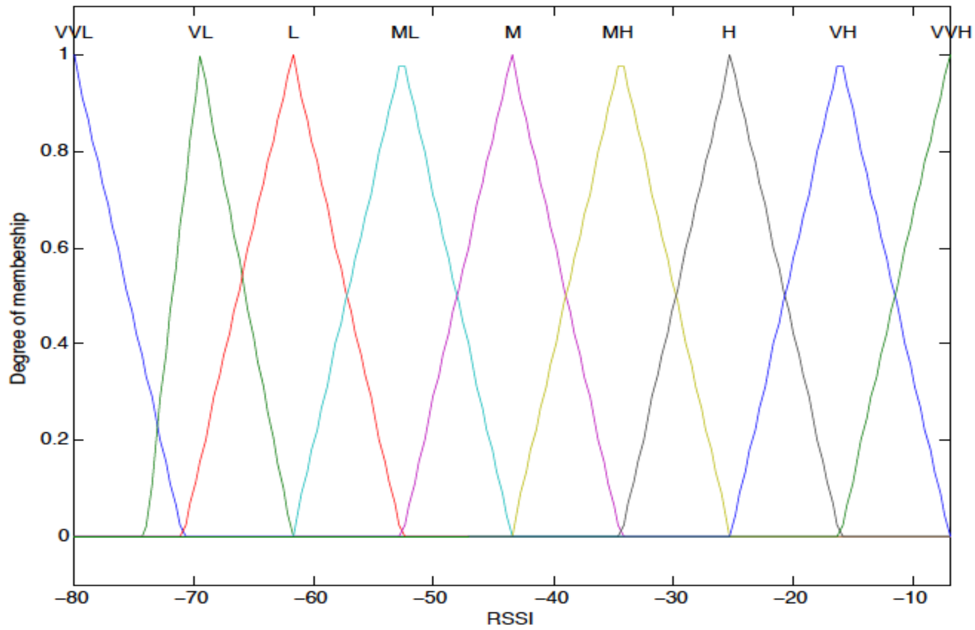

Figure 5.3: Input membership functions

On the other hand, the output membership function of the sugeno fuzzy inference is the weight of each anchor node for a given sensor node which takes value $[0, w_{max}]$, where w_{max} is the maximum weight that is one. The output membership function distribute into nine linear functions such as VVL, VL, L, ML, M, MH, H, VH, VVH.

To find the range of output of each membership function, the logarithm of each RSSI in different distance should be mapped to linear variable between [0,1]. On the other hand, the RSSIs should be mapped among [0,1] in nine variables of weights.

As can be seen the minimum and maximum of weights are always zero and one, therefore, the seven remaining membership functions of output take values by adding 1.42 to the range of their prior membership functions. In fact, 1.42 is achieved by dividing ten meter by seven, which is the number of remaining membership functions.

Indeed each range of membership function is calculated as follows:

$$\alpha = \frac{\Delta Y}{\Delta X} \tag{5.1}$$

Where α is the output range of membership function, ΔY is the range of membership function for each triangle RSSI and ΔX is achieved by the following relation:

$$\Delta X = \frac{\Delta p}{1.42} \tag{5.2}$$

Where Δp is the difference between the range of each membership function's each distance and the range of the membership function for the next distance.

Furthermore, nine membership functions have been implemented to decrease the error and increase the accuracy of each estimated sensor nodes.

The rules considered for this sugeno fuzzy method are in terms of the power of RSS. If the anchor node receives a high power from the sensor node, it indicates that the sensor node is near to the anchor node. On the other hand, if the senor node connected to the anchor node receives a low power, it shows that the sensor node is far from the anchor node. Table 5.1 shows the rules of sugeno fuzzy system.

Table 5.1: Fuzzy Logic Rules

RULES	IF: RSSI IS	THEN: WEIGHT
RULE 1	V V LOW	V V LOW
RULE 2	V LOW	V LOW
RULE 3	LOW	LOW
RULE4	MEDIUM LOW	MEDIUM LOW
RULE 5	MEDIUM	MEDIUM
RULE 6	MEDIUM HIGH	MEDIUM HIGH
RULE 7	HIGH	HIGH
RULE 8	V HIGH	V HIGH
RULE 9	V V HIGH	V V HIGH

Figure 5.4 indicates the surface of the fuzzy system, which shows the weight corresponding to the RSSI values.

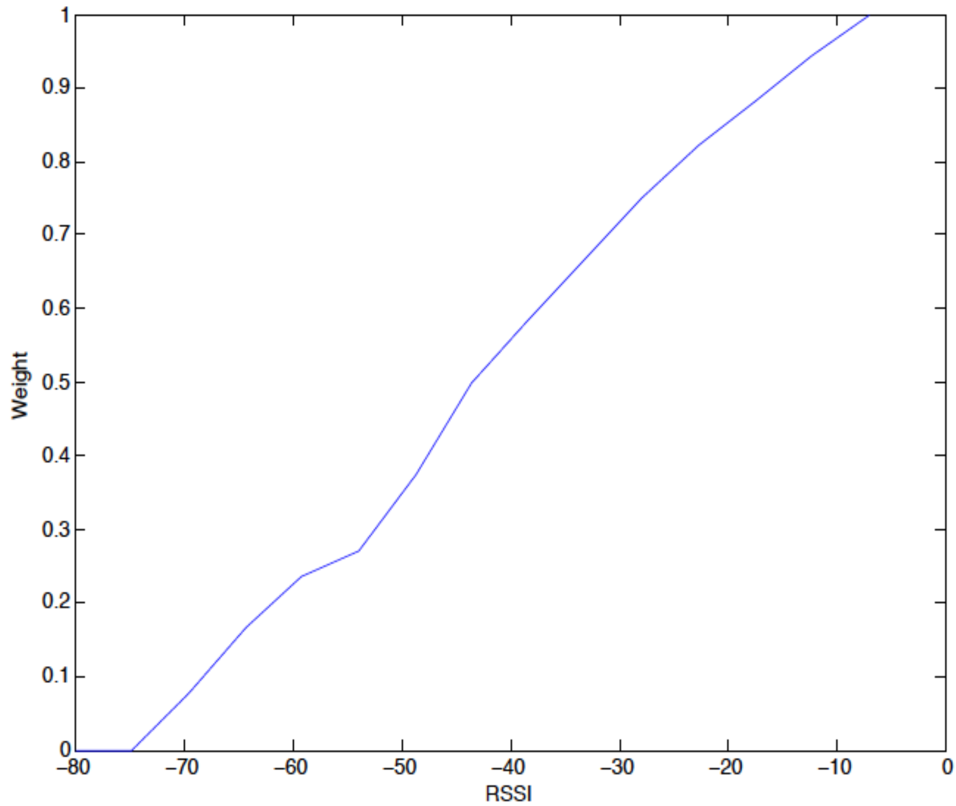

Figure 5.4: RSSI vs. Weight (Surface)

5.1.1 Simulation

The algorithms are coded in Matlab where the sensor nodes are distributed randomly in a square region that is 10 meters for each side. The first step is to estimate RSS by the following formula:

$$RSSI = -(10n\log_{10}(d) + alpha) \tag{5.2}$$

Where d is the distance of each sensor node to the anchor nodes, which is calculated by the following equation:

$$D = (\sqrt{(x_i - x_{rand})^2 + (y_i - y_{rand})^2}) \tag{5.3}$$

x_i and y_i are coordinates of each anchor nodes, x_{rand} and y_{rand} are coordinates of sensor nodes that are located randomly in the region as shown in Figure 5.5.

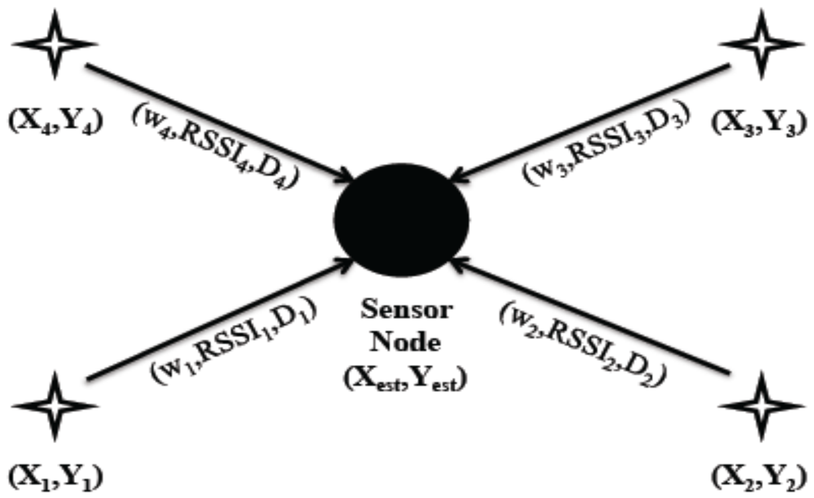

Figure 5.5: An example of connectivity of RSSI, Distance and Weight

On the other hand, in equation (5.2), $n = 3.25$ is the path loss exponent, which may take different values and may be affected in different environments. Alpha is constant, and it is the RSSI value of the sensor node that is located in 1-meter distance of anchor node, so alpha is considered to be -40dB for this implementation.

Figure 5.6 shows the propagation of RSSI to distance. As can be seen from the figure, in 1m the RSSI is -40dB. The minimum of RSSI is -72.5dB which is achieved in 10 meter. Hence, this figure indicates that the propagation of received signal strength to distance is a logarithmic function.

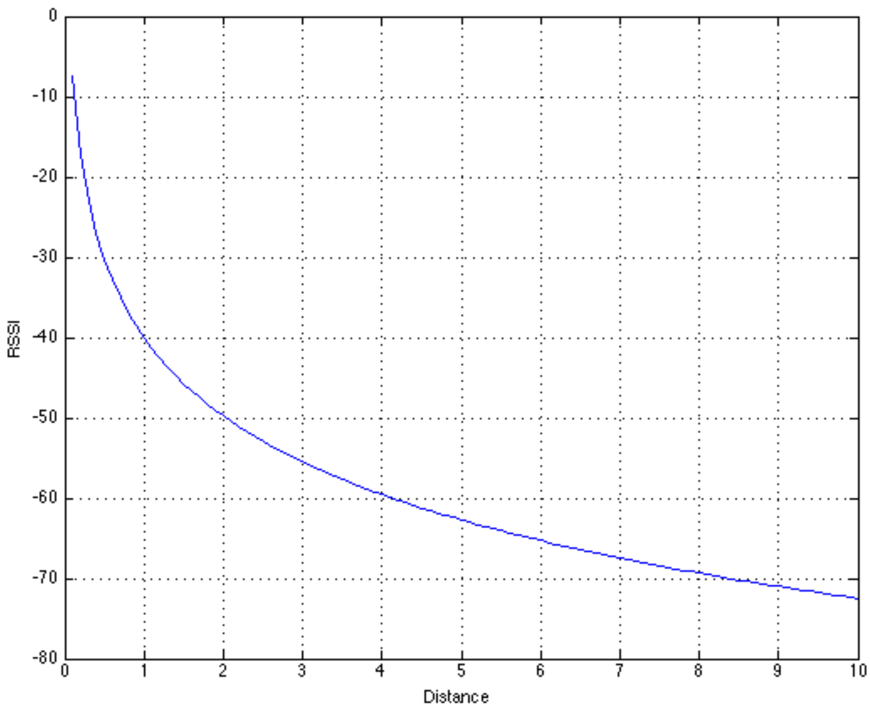

Figure 5.6: Receive Signal Strength vs. Distance

After estimating RSSI for each anchor node, each of them has a specific weight. Hence RSSIs are inputs and weights are outputs for the sugeno fuzzy inference.

The centroid method is the scenario which is considered in this implementation. Therefore, for estimating the coordinates of the sensor nodes, the centroid formula is used, as follows:

$$(X_{est}, Y_{est}) = \left(\frac{x_1 w_1 + \ldots + x_n w_n}{\sum_{i=1}^{n} w_i}, \frac{y_1 w_1 + \ldots + y_n w_n}{\sum_{i=1}^{n} w_i}\right) \tag{5.4}$$

Where (X_{est}, Y_{est}) are the coordinates of sensor locations, x_i and y_i are the position of each anchor node and w_i is the weights of each anchor node to the sensor node.

Figure 5.7 shows the result of the simulation of localization by using Matlab.

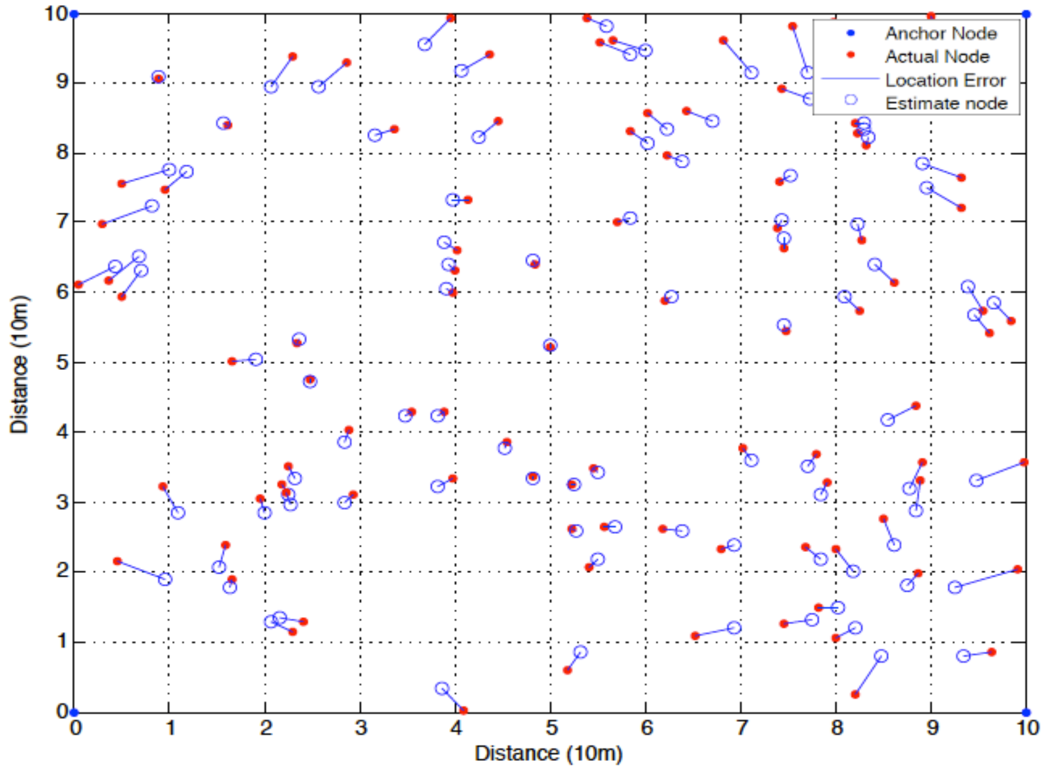

Figure 5.7: Simulation result of localization by sugeno fuzzy method

As shown in this figure, the region is 10 meter square, where the anchor nodes are located at (0,0), (10,0), (10,10) and (0,10). The 100 sensor nodes are randomly deployed in the region. All sensor nodes receive four RSSI from the anchor nodes. After estimating the RSSIs, each sensor node have four weights that are estimated by the sugeno fuzzy system. The centroid relation is used for estimating the coordinates of the sensor nodes.

As shown in Figure 5.7 the random nodes are the solid circles and the estimated nodes are the empty circles. The line between the random and estimated nodes is the error of location. Hence, the error in the location between actual and estimated nodes is calculated by the following relation:

$$Location\ error = \sqrt{(x_{est} - x_a)^2 + (y_{est} - y_a)^2} \tag{5.5}$$

In order to estimate the position errors for all the estimated and actual nodes, the following relation is used:

$$Average\ location\ error = \frac{\sum \sqrt{(x_{est} - x_a)^2 + (y_{est} - y_a)^2}}{N} \tag{5.6}$$

Where N is the total number of sensor nodes. Figure 5.8 indicates the simulation error results of localization in this implementation for 100 nodes.

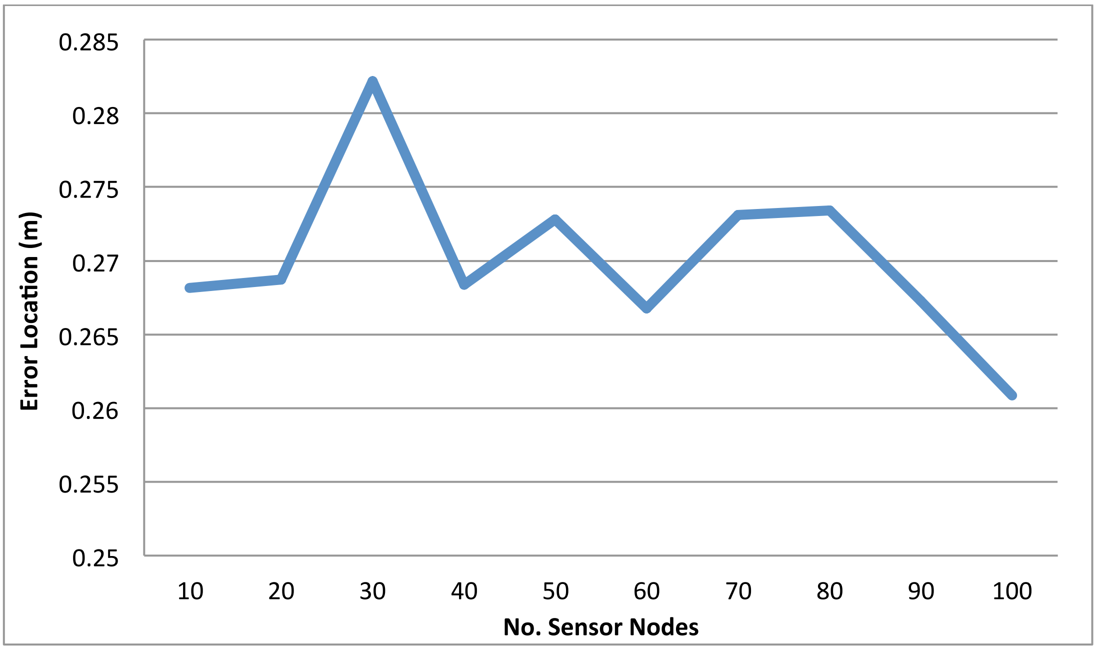

Figure 5.8: Location Error Result

As can be seen, the average of error location is maximum for 30 sensor nodes used in the region, on the other hand the error location for 100 sensor nodes deployed in the region is minimum. Hence, the average error location for differenet number of sensor nodes, is 0.26 meter. Therefore, the error locations does not depond on the number of sensor nodes that is deployed in the region.

After estimating the location of sensor nodes in the simulation, Additive White Gaussian Noise (AWGN) is added to the RSSI with 10 SNR (Signal to Noise Ratio).

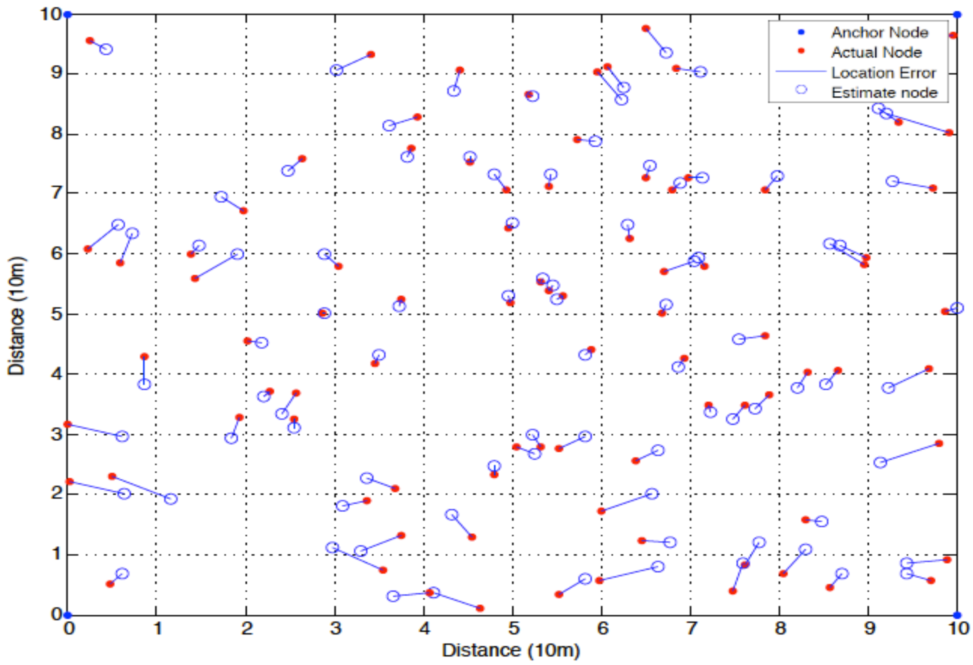

Figure 5.9: The location of sensors with AWGN

Figure 5.9 indicates the location of random node and sensor nodes when AWGN is added to the simulation.

As can be seen in this figure, there is an error between the actual and estimated nodes, hence Figure 5.10 shows the error location for 100 nodes in the region with AWGN.

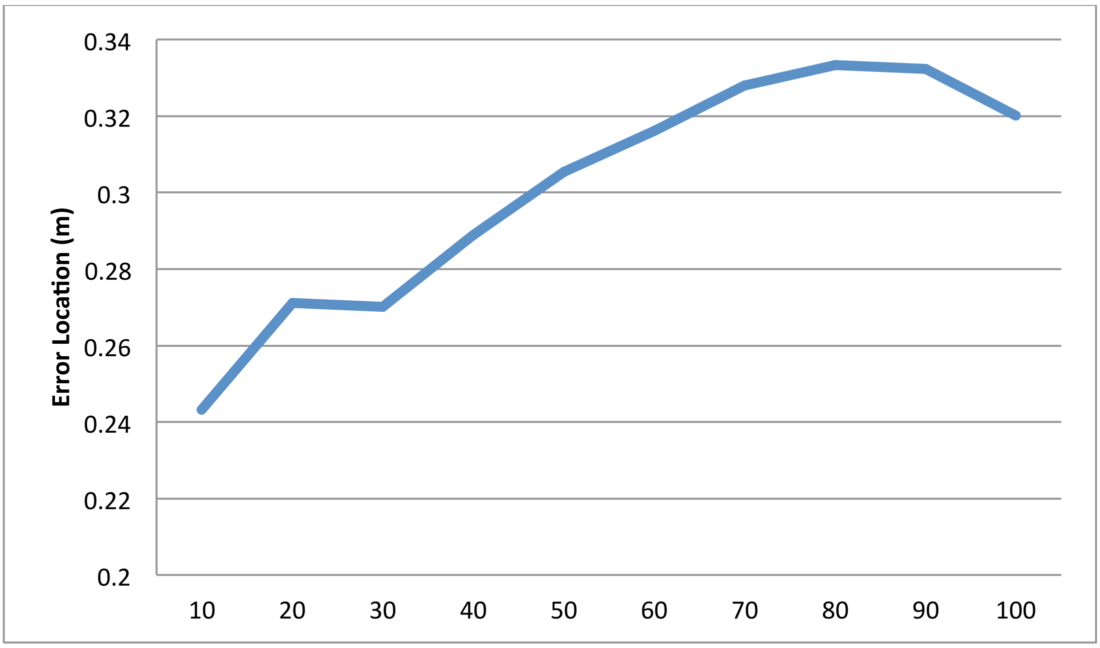

Figure 5.10: Location Error Result with AWGN

As can be seen, the average error location for 10 sensor nodes is approximately 0.24, however, the average error location is increased to 0.33 for 80 sensor nodes in the region. After that, the average error locations for 90 and 100 number of sensor nodes, is decreased. Hence, the average error location in differenet number of sensor nodes with AWGN is 0.3 meter.

Table 5.2 shows the error location for both areas of the simulation, with and without AWGN.

Table 5.2: The Result of With and Without AWGN

	Min Error Location	Max Error Location	Average Error Location
Centroid Method without Fuzzy	0.10	4.35	2.95
Fuzzy	0.005	0.70	0.26
Fuzzy + AWGN	0.01	0.79	0.30

As can be seen minimum, maximum and average error locations of sensor nodes in both centroid method and fuzzy are shown. Hence, the result of centroid method error location comparing to the fuzzy is very high. For fuzzy, the result error location for both with and without AWGN also shown. The result of average errors in both areas are close to each other. According to this table and comparing the minimum and maximum of both results of error location in the areas, we see that this implementation has the highest accuracy in different environments.

5.2 Experimentation

The experiment of this method is done in the region with 10 meter square. The RSSIs have been taken form each node in this experiments have different values in comparison with the RSSIs that have been achieved in the simulation. Figure 5.11

indicates the result of RSSIs in simulation and experimentation. The blue line in this figure indicates the result of RSSI in the simulation by Matlab and the other one, which is the red line, the result of RSSI taken from the experimentation. In fact there is no much difference between RSSIs taken from simulation and experimentation, which indicates the exactness of the results in this implementation.

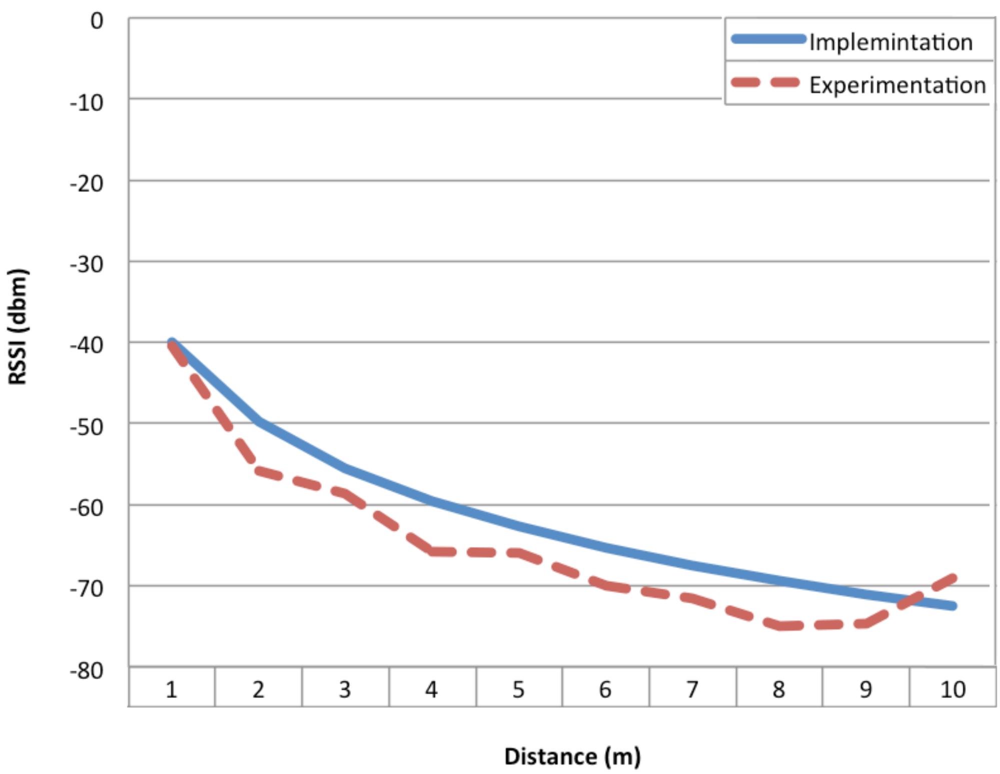

Figure 5.11: RSSIs in Simulation and Experimentation

The anchor nodes are located in the mentioned positions as (0,0), (0,10), (10,0) and (10,10). After placing the four anchor nodes, different RSSI values are obtained from four anchor nodes by the sensor node.

In the experiment, some nodes are located randomly in the region in order to obtain their RSSI form the anchor nodes. The four RSSIs values that are obtained correspond to their distance from the anchor nodes. Therefore, each RSSI is then fed to the fuzzy system to get the corresponding weights.

This experiment is repeated 6 times for 6 different positions of the sensor nodes. Figure 5.12 shows the position of one of the random nodes, which is located in (1,1).

Figure 5.12: Sensor node in position (1,1)

As can be seen from Figure 5.10 the sensor node is close to the first anchor (0,0), so it receives the highest RSSI in comparison with the other anchor nodes. The centroid relation for the sensor nodes is represented in Table 5.3.

Table 5.3: The result of Experimentation. The power values are in dBm and the locations are in metres.

(X_a,Y_a)	RSSI from (0,0)	RSSI from (0,10)	RSSI from (10,0)	RSSI from (10,10)	(X_{est},Y_{est})	Error Location
(1,1)	-41	-71.5	-68.5	-75.5	(1.37,0.74)	0.45
(4,3)	-57	-69	-63	-68	(4.67,2.98)	0.67
(2,7)	-67	-65	-75	-70	(2.10,6.56)	0.44
(5,5)	-69	-71	-70	-68	(5.52,4.98)	0.52
(7.5,7.3)	-75	-68	-67	-55	(7.89,7.54)	0.46
(9,5)	-73	-74	-64	-65	(9.21,4.34)	0.69

As can be seen from the table the node at (1,1) receives the highest RSSI from the anchor node at (0,0), which is the nearest anchor node. On the other hand, that node receives the minimum RSSI form the anchor node at (10,10) which is located at the fmaximum distance from that anchor node.

As given in Table 5.3, the error location obtained by the experimentation is not out of range of the error location which is obtained in the simulation, and also the average error in the experimentation is 0.53 while the average error in the simulation has been obtained as 0.26. Hence, the difference is not much in the error location between the analytical and experimental results.

As a result, the results are comparible with the existing methods in the litreture. Table 5.4 represents the comparison results of error location in both implementation and experimentation.

Table 5.4: Comparison Result in Error Location

Proposed Results by Fuzzy Logic	Average Error Location	Average Error in Experimental
This Thesis	0.26	0.53
S. Yun, J. Lee, W. Chung, E. Kim, S. Kim"*A soft Computing approach to localization in WSN* " 2009	0.78	0.80
V. Kumar, A. Kumar, S. Soni " *A new fuzzy based localization error minimization approach with optimize* " 2011	0.59	0.94

It can be seen that, the result of error location achiveied has improved by sugeno fuzzy comparing with other methods. Therefore, the minimum error has been obtained as 0.26. On the other hand, the error location in the real test is also decreased by more than 30 percent of error location.

Chapter 6

CONCLUSION AND FUTURE WORK

Knowledge of node location is required to be reported in different situations such as the origin of events, assist group querying of sensors and also to answer the questions on the network coverage. Hence the node localization is a challenging topic in wireless sensor networks.

The range free localization method is very simple since there is no need to have complicated hardware. The range free method has different techniques to estimate the position of a sensor node in a specific region. In this thesis Centroid localization has been utilized for implementation and experimentation.

The estimation of each sensor node's location has been implemented by RSSI. Therefore RSSI is achieved by estimating the distance between each anchor and the sensor node.

The sugeno fuzzy inference is used to simulate for estimating the location of each sensor nodes. In fact all the RSSIs are fed to the fuzzy system to achieve the weights to be used in the centroid relation in order to estimate the location of the sensor nodes.

The weights are the main parameters in the centroid relation, which are the output of the fuzzy system. In fact, the sugeno fuzzy system receives RSSIs as inputs to map to the outputs, which are the weights of each anchor node with respect to the sensor node.

After estimating the weights by fuzzy system, the centroid relation estimates the location of each sensor nodes. Hence there is an error in the location between the random and the estimated node.

The analysis is also performed by adding AWGN. As can be seen in the implementation, the difference in error location is negligible.

The experiment has been repeated 6 times for 6 sensor nodes in the region. 6 sensor nodes deployed randomly in the region and four anchor nodes have been placed at (0,0), (10,0), (10,10) and (0,10). After estimating the RSSIs and the weights, it is observed that there are some errors in the location between the actual and the estimated node. Hence, the average error location which has been computed in the real test, is not large comparison to the average error location obtained in the analytical test.

6.1 Future Work

As a future work, increased number of anchor nodes may be used to estimate the location of sensors with less error. Therefore, each sensor node that is recognized with a known position, will be used as one of the anchor nodes. Hence, the new sensor nodes for estimating the coordinate will use the nearest anchor nodes which helps to decrease the cost of computation and also improves the accuracy of locating the sensor nodes.

REFERENCES

[1] Estrin. D, Elson. J, *Sensor Networks: A Bridge to the Physical World*. Springer, 2004.

[2] Su.W, Sankarasubramaniam.Y,Cayirci. E Akyildiz. I, "A survey on sensor networks " in *Communications Magazine*, pp. 112-114, 2002.

[3] Abdelzaher. T, Lu. C, Sha. L, Hou .J, Stankovic. J, "Real-time communication and coordination in embedded sensor networks " , vol. 91, pp. 1002-1022, 2003.

[4] Kumar. C, Chong. S, "Sensor networks: Evolution, opportunities and challenges " , vol. 91, pp. 1247-1256, 2003.

[5] Ammer. J, da Silva Jr. J, Patel. D , Roundy. S, Rabaey. J, "Picoradio supports ad hoc ultra-lowpower wireless networking " *Computer Magazine*, vol. 33, pp. 42-48, 2003.

[6] Hannikainen. M, Hamalainen. TD, Kohvakka. M, "High-performance multi-radio WSN platform " in *2nd International workshop on Multi-hop Ad Hoc Networks: From Theory to Reality*, Italy, pp. 95-97, 2006.

[7] Hannikainen. M , Hamalainen. TD, Kohvakka. M, "Wireless sensor prototype platform " in *Int'l Conf. on Industrial Electronics, Control and Instrumentation (IECON'03)*, Virginia, USA, p. 860–865, 2003.

[8] Mattern. F, Romer. K, "The design space of wireless sensor networks "

Wireless Communications, vol. 11, pp. 54-61, 2004.

[9] Kasten. O, Mattern. F, Romer. K, "Middleware challenges for wireless sensor networks " *SIGMOBILE Mobile Computing and Communications Review* , vol. 4, pp. 59-61, 2002.

[10] Oorschot. P, Vanstone. S, Menezes. A, *Handbook of Applied Cryptography*. CRC Press, 1996.

[11] Stallings. W, *Network and Internetwork Security: Principles and Practice*. Prentice-Hall, 1995.

[12] Kohvakka. M, Suhonen. J, Hamalainen. P, Hannikainen. M,Hamalainen. TD, Kuorilehto.M, *Ultra-Low Energy Wireless Sensor Networks in Practice*. John Wiley, 2007.

[13] Lee. J, Chung. W, Kim. E, Yun. S, "Centroid localization method in wirelesssensor networks using TSK fuzzy modeling " in *International symposium onadvanced intelligent systems*, Sokcho, Korea, pp. 971-974, 2008.

[14] Widmer. J, Harttenstein. H Mauve. M, "A Survey on Position Based Routing in Mobile Ad-Hoc Networks " *Network Magazine*, vol. 15, pp. 30-39, 2001.

[15] Jannotti. J, DeCouto. D. S. J, Karger. D. R, Morris .R, Li. J, "A Scalable Location Service for Geographic Ad-Hoc Routing " in *Sixth Annual International Conference on Mobile Computing and Networking*, Boston,

Massachusetts, USA, pp. 120-130, August 2000.

[16] Shaha. U, Desai. U. B, Merchant. S. N, Patil. M. M, "Localization in Wireless Sensor Networks using Three Masters " in *International Conference on Personal Wireless Communications ICPWC* , 2005.

[17] Reijers. N, Langendoen. K, "Distributed localization in wireless sensor networks: A quantitative comparison " *Computer Networks* , vol. 43, pp. 499-518, 2003.

[18] Jaehun. L, Wooyong, Sukhyun.Y, "A soft computing approach to localization in wireless sensor networks " vol. 36, p. 7552–7561, 2009.

[19] Sarigiannidis. G, *Localization for Ad Hoc Wireless Sensor Networks*. Netherlands. Technical University Delft, August 2006.

[20] X. Li, Y. Shang, D. Ma, H. Shi, "Cramer-Rao Bound Analysis of Quantized RSSI Based Localization in Wireless Sensor Networks " in *International Conference on parallel and distributed systems(ICPAD'05)*, 2005.

[21] Xiaoyan. Li , Martin. R. P, Elnahrawy. E, "The Limits of Localization Using Signal Strength: A Comparative Study" *SECON*, pp. 406-414, October 2004.

[22] Chengdu. H, Tian. H, "Range-Free Localization Schemes for Large Scale Sensor Networks " in *MOBICOM*, pp. 81-95, 2003.

[23] Huang. C, Blum. B, Stankovic. J. A, Abdelzaher.T, He. T, "Range-Free localization schemes in large scale sensor networks " in *International*

Conference on Mobile Computing and Networking (Mobicom) , 2003.

[24] Park. H, Srivastava .M, Savvides. A, "The bits and flops of the N-homultilateration primitive for node localization problems " in *International Workshop on Wireless Sensor Networks and Application*, 2002.

[25] Wang. F .B, Wang. J. G, "Distributed node localization algorithms of wireless sensor networks" *Computer Application*, vol. 25, 2005.

[26] Heidemann .J, Estrin. D, Bulusu. N, "GPS-less Low Cost Outdoor Localization for Very Small Devices " *Personal Communications Magazine*, vol. 7, pp. 28-34, 2000.

[27] LotfiZadeh. A, *Fuzzy Set Information and Control.*, 1965, vol. 8.

[28] Hellmann. M, *Classification of fully polarimetric SAR for Cartographic Applications*. Germany: DLR Forschungsbericht , 2000.

[29] Prade. H, Dubois. D, *Fuzzy Sets and Systems: Theory and Applications*. New York. Academic Press, 1980.

[30] Mamdani. E. H, "Applications of fuzzy logic to approximate reasoning using linguistic synthesis " *Transactions on Computers*, vol. 26, pp. 1182-1191, 1977.

[31] Yager. R, *Fuzzy Sets and Systems On a general class of fuzzy connectives.*, 1980.

[32] Lee. C, "Fuzzy logic in control systems: fuzzy logic controller-parts 1 and 2 " *Transactions on Systems, Man, and Cybernetics* , vol. 20, pp. 404-435, 1990.

[33] Mamdani. E. H, "Advances in the Linguistic Synthesis of Fuzzy Controlers " *International Journal of Man Machine Studeis*, vol. 8, pp. 669-678, 1976.

[34] Niku. S, *Introduction to robotics analysis, systems, applications*. California. Polytechnic san luis obispo, 2001.

[35] Mamdani. E. H, Assilian. S, "An Experiment in Linguistic Synthesis with Fuzzy Logic Controller " *International Journal of Man-Machine Studies*, vol. 7, pp. 1-13, 1975.

[36] Wang. L, *Adaptive fuzzy systems and control: design and stability*.: Prentice Hall, 1994.

[37] Sugeno. M, "Fuzzy measures and fuzzy integrals: a survey," *Fuzzy Automata and Decision*, pp. 89-102, 1977.

[38] Filev. D, Yager. R, "Generation of Fuzzy Rules by Mountain Clustering " *Journal of Intelligent & Fuzzy Systems*, vol. 2, pp. 209-219, 1994.