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## **Localization in WSN Based on Graph and RSSI Methods**

**A Thesis**

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for the Degree of Master in Sciences \ Computer Science**

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**1445. A.H.**

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

﴿ وَلَقَدْ آتَيْنَا دَاوُودَ وَسُلَيْمَانَ عِلْمًا وَقَالَا  
الْحَمْدُ لِلَّهِ الَّذِي فَضَّلَنَا عَلَى كَثِيرٍ مِنْ عِبَادِهِ  
الْمُؤْمِنِينَ ﴾

صَدَقَ اللَّهُ الْعَظِيمَ

الجزء ١٥

## *Dedication*

*I dedicate this thesis*

*To my father, who holds a special place in my heart second only to Allah and His Prophet Muhammad.*

*To my beloved mother, whose love and care have shaped me into who I am today.*

*To my beloved brothers and sisters, whose bond is a source of strength and support.*

*To my dear husband and children, the pillars of my happiness and the center of my world.*

*My loyal friends, your steadfast support holds immeasurable value in my life.*

*Zainab*

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## **Abstract**

In various Wireless Sensor Network (WSN) applications, obtaining precise location information of nodes is imperative. These applications encompass a broad spectrum, including location-based routing, tracking systems, dynamic networks, and health monitoring systems. The primary focus of most literature in this domain revolves around the dual objectives of minimizing error and conserving energy. This thesis endeavors to introduce an innovative approach for localizing the coordinates of nodes within WSNs.

The approach leverages the use of graphs and Received Signal Strength Indicator (RSSI) measurements to estimate the distances between each sensor node and its neighboring nodes in the target field. Subsequently, a central sink node collection this information to construct the network graph and estimate the precise node locations. The proposed algorithm has been meticulously implemented using the Net Logo simulation platform and C#. The performance assessment of this methodology is grounded in the twin metrics of accuracy and energy consumption of the sensor nodes.

The experimental results underscore the efficacy of the approach, as it tangibly enhances location accuracy while mitigating location errors. In comparison to existing literature, the proposed method exhibits commendable outcomes in terms of accuracy, with an average error falling within the narrow range of 0.73 to 1.23 meters.

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## List of Abbreviations

<b>Abbreviations</b>	<b>Meaning</b>
<b>AOA</b>	<b>Angle of Arrival</b>
<b>AN</b>	<b>Anchor Node</b>
<b>CR</b>	<b>Communication Range</b>
<b>GBLE</b>	<b>Graph Based Localization Estimation</b>
<b>GPS</b>	<b>Global Positioning System</b>
<b>RSSI</b>	<b>Received Signal Strength Indicator</b>
<b>RN</b>	<b>Reference Node</b>
<b>TDOA</b>	<b>Time Difference of Arrival</b>
<b>TOA</b>	<b>Time of Arrival</b>
<b>UN</b>	<b>Unknown Node</b>
<b>WSN</b>	<b>Wireless Sensor Network</b>

## *Chapter One*

### *General Introduction*

#### **1.1 Introduction**

A commonly utilized technique for gathering environmental data is known as Wireless Sensor Network (WSN), and many educations have used it [2]. A WSN is a group of tiny sensors that are connected wirelessly, enabling them to communicate with each other and identify particular events within a designated area [3]. In environments where network devices, resources, and computation power are severely constrained by their small size, several challenges arise due to the limitations imposed by energy consumption [4].

The localization of WSNs is a significant area of research and development, mainly due to the energy limitations of small sensor nodes. Anchor nodes play a crucial role in helping these unknown nodes to determine their locations accurately. This concept is essential for various applications, including environmental monitoring, asset tracking [3].

WSNs are well-suited for a wide range of applications, including those mentioned in Figure 1.1



**Figure 1.1 Illustrates a Spectrum of Localization Applications for Wireless Sensor Networks**

These nodes are equipped with sensors to detect various physical phenomena, such as temperature, humidity, light, sound, motion, or specific chemicals [4]. The deployment strategy of WSNs in WSN can significantly impact the network's performance and efficiency. Two common deployment strategies are deterministic deployment and random deployment, each suited to specific applications based on the sensor area and surrounding conditions [5]. Finding the location of a sensor node could be a challenging operation that is important for many WSN applications [6]. The position data of each sensor node is essential for numerous scenarios and services in the majority of applications. However, that because without knowledge about the sources of the data, such as forest fire detection or fighting, the collection of information without position is meaningless [7]. The critical phase in the sensor node tracking

messages is the location of the event or the node from which information will be gathered [4, 8].

These position estimate limitations have been solved through several localization techniques for WSNs. There are two types of these localization techniques: range-based and range-free [4, 6, 8]. The range-based method makes use of the estimated angle and distance to calculate position using geometrical concepts. The form comparison and connecting methodology are used by the range-free method to estimate position. In this case, hop counts are used rather than direct distance calculations. Following the calculation of the number of hops, the shortest path is used to determine the length between the nodes, and the computation of location is done using geometrical principles [9].

## **1.2 Problem Statement**

In WSNs, various applications demand not only sensing data but also the crucial metadata of sensor node locations. Equipping every node in a WSN with GPS capabilities, while effective, can prove cost-prohibitive and energy-intensive. Consequently, devising solutions that rely on a limited number of anchor nodes to achieve the required precision, within reasonable cost constraints, remains a persistent challenge in the domain of WSNs.

### 1.3 Objectives of The Study

1. Developing an innovative methodology for estimating the geographic coordinates of sensor nodes, leveraging parameters such as Received Signal Strength Indicator (RSSI), graph theory, routing, and message propagation.
2. Designing an approach that minimizes the reliance on anchor nodes while preserving the desired level of precision, thereby optimizing the cost factor.
3. Achieving a balance between enhancing localization accuracy, reducing computational demands, and conserving energy resources, ensuring adaptability to set of applications and available resources.

### 1.4 Related Works

The localization of sensor nodes within WSNs is an imperative research facet, given its pivotal part in numerous sensor applications. A plethora of algorithms and methodologies has been proposed to address this challenge, as outlined below.

In [10]. Rai and Varma (2016), introduced the application of rigid graph-based localization, employing trilateration with bearing and distance information. By establishing a rigid grid within the WSN graph, this approach minimizes the impact of noisy distance data, yielding an impressive average error rate of 5%.

In [11]. Rahman and Hanuranto (2017), delved into RSSI-based localization, showcasing the exceptional accuracy of range-based trilateration and iterative multi-alteration methods. Randomly uniform deployment scenarios underscore the superiority of trilateration.

In a distinct vein, [12] Alomari and Comea (2018), introduced an entirely new paradigm in anchor-assisted mobile localization mapping

within WSNs. This method departs from traditional static models, as it posits that all network nodes possess the capability to acquire translational information, thereby enabling them to estimate their respective locations with heightened precision. Moreover, this pioneering model effectively surmounts the collinearity challenge and furnishes a suite of critical metrics for evaluation, encompassing accuracy, power consumption, mobile broadcast precision, translation ratio, and path length.

In [8], D.Xue (2019), an improved DV-Hop algorithm is presented, incorporating distance modification and hop shortening techniques. Leveraging Received Signal Strength Index (RSSI) range technology, this method rectifies minimum hop distances and refines average hop distances through weighted mean values of estimated and actual errors. Implementation via Mat lab simulations validates the superior accuracy of this updated algorithm.

In [6]. S.Naguib (2020), Presented a novel localization system comprising iterative multi-alteration, atomic multi-alteration, and distance estimation components. Simulation results reveal that iterative multi-alteration outperforms atomic multi-alteration in terms of localization error and the proportion of locally located sensor nodes.

In [13]. Ibrahim et al, an innovative algorithm is introduced for locating unknown nodes. The Triple Mobile Anchors with Localization (TMAL) model utilizes Relative Side Coordinates (RSC) in estimating sensor locations within the WSN. This model's strength lies in its mobile anchor nodes, with stored tethering node locations facilitating precise distance-based computations. Central to the TMAL framework are three strategically positioned tethering nodes whose locations are meticulously recorded at any given moment. This seemingly simple requirement engenders profound implications for the accuracy of distance-based

calculations, particularly within the context of communication among mobile anchors.

In [4], Kanwar and Kumar (2021), introduced an enhanced DV-Hop localization method, bolstered by the Root Runner Algorithm (RRA), which adjusts the inter-hop distances of connected sensors using a correction factor. This approach outperforms conventional localization algorithms, reducing localization errors and computational overhead. However, certain limitations.

In [9]. Sharma and Singh (2021), a straightforward RSSI-based technique is proposed for estimating unknown node locations, eliminating the need for extra hardware or data connections. The simplicity of this method, with reduced computational and communication overhead, is its hallmark, relying on four fixed anchor nodes.

In [5]. Bhat and S.KV(2022), investigated localization, diffusion, and hole-finding challenges in randomly dispersed WSNs by uncertain node positions. Leveraging an algorithmic optimization approach (AOA), this method delivers exceptional accuracy with an error rate below 0.27% and an average localization error within 5 meters.

Below Table 1.1 illustrate summary of related works.

**Table 1.1: The Summary of Related Works**

#REF	Year	# AN	# UA	Transmission Range	Method	Anchor Type
[10]	2016	3	100 - 120	70 – 100 m	Trilateration Technique	Static
[11]	2017	(31-36),16	M	15 – 35 m	Trilateration , Iterative Multi-Alteration	Static
[12]	2018	1	250	5- 20 m	H-Curves	Mobile
[8]	2019	0.05-0.3	200	30 m	Maximum Likelihood Method	Static
[6]	2020	10% ,20%,30%,40% ,50%	100	25 -30 -35 m	Iterative , atomic Multi-alteration	Static
[13]	2020	3	50 - 100	10 -35 m	RSSI, Receive Signal Strength	Mobile
[4]	2021	25-150	100- 350	15-35 m	Hyperbolic Method ,The Runner-Root Algorithm (RRA)	Static
[9]	2021	4	50 – 100	_	RSSI Information ,Trilateration	Static
[5]	2022	20%	500 - 2000	12 – 24 m	Arithmetic Optimization Algorithm (AOA)	Static
Proposed system	2023	3	70-100-120	20-35 m	Graph and RSSI	Static

## 1.5 Thesis Organization

The thesis is organized into five distinct chapters, each contributing to an inclusive exploration of the subject matter:

**Chapter Two: Fundamentals of WSN Localization** Chapter Two delves deeply into the fundamental concepts underpinning localization challenges within WSN, providing a robust theoretical framework.

**Chapter Three: The Proposed Model and its Key Parameters** Chapter Three meticulously describes the proposed model, elucidating its intricacies and highlighting the critical parameters that drive its effectiveness.

**Chapter Four: Results and Discussion** Chapter Four presents the outcomes of the research effort, offering a comprehensive analysis and discussion of the obtained results.

**Chapter Five:** This chapter shows the major conclusions and suggestions for future action from the results of the proposed system.

## *Chapter Two*

### *Theoretical Background*

#### **2.1 Introduction**

In this chapter, we embark on a comprehensive exploration of WSNs and their localization methods. We commence by establishing fundamental definitions and terminology pertaining to WSNs. Additionally, we delve into the essential components of a sensor node, explore the intricacies of node positioning, and elucidate fundamental methods for determining node positions. Furthermore, we touch upon key applications and delve into the performance metrics associated with localization algorithms.

#### **2.2 Wireless Sensor Networks**

The WSNs are made up of numerous sensor nodes that work together to understand data collaboratively and distribute sensing responsibilities for a variety of critical applications. The adoption of these sensors might improve wildlife survival and roadway safety while also speeding up rescue efforts. Micro, electro-mechanical systems (MEMS) have evolved and advanced to the point where they may now be used to create compact, low-power, low-cost sensors that can communicate over short distances [14].

### 2.2.1 Sensor Nodes in WSNs

A sensor node comprises several integral components, including computing power, memory, a radio transceiver, a power source, and sometimes GPS functionality, as depicted in Figure 2.1 [1]. These sensor nodes come in various types tailored to specific use cases and environments. There are many types of sensor nodes based on their use and environment [15].

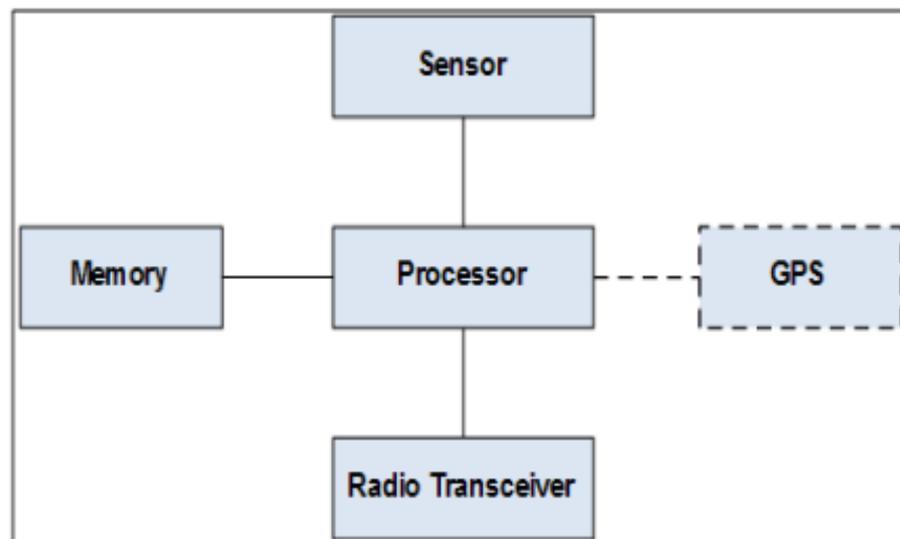


Figure 2.1 Overview of the Main Sensor Node Hardware Components[1]

A sensor node essentially comprises four fundamental units:

**1. Sensing Unit:** Responsible for monitoring and detecting environmental changes, the sensing unit captures data related to light, sound, vibration, motion, heat, humidity, or wind, depending on the node's capabilities and application. It excels at sensing, measuring, and collecting various types of data from the environment [16, 17].

**2. Processing Unit:** The processing unit handles data processing and computation tasks, making it pivotal for extracting meaningful insights from the collected data [17].

**3. Transceiver Unit:** This unit facilitates communication and data exchange via radio communication. It manages data transmission, reception, and interactions with central nodes and neighboring nodes. Notably, it consumes the most energy among all sensor node units. This unit uses radio communications for its communications and information exchange to transmit and receive data, communicate with the central node to deliver data, and communicate with nearby nodes. Of all the sensor node units, this one uses the most energy [18]. The sensor node's functionality is restricted to three states: active mode (during which the transmission and reception processes are completed), idleness (during which the transmitter and receiver are turned off to save power), and sleep [19].

**4. Power Unit:** The power unit serves as the energy source for other node functions, ensuring the node's operational capabilities [17].

Sensor nodes can either be stationary or mobile, contingent upon the deployment context. Depending on the movement characteristics of sensor nodes, whether unknown or anchor nodes, four deployment types exist: mobile sensor nodes with both unknown and anchor nodes, static sensor nodes with both unknown and anchor nodes, mobile unknown nodes with static anchor nodes, and static unknown nodes with mobile anchor nodes [20]. Energy conservation in sensor nodes depends on factors such as the node count, additional secondary units, processing load, Communication Range CR, and algorithmic complexity. Each sensor node relies on an independent battery as its power source.

Battery depletion can render a node inoperative, posing a challenge for nodes placed in hard-to-reach locations. Effectively managing energy consumption within WSNs is imperative to extend the network's lifespan. Sensor nodes in WSNs can exhibit varying degrees of mobility based on the specific deployment environment and application requirements. Depending on the movement characteristics of sensor nodes [20]:

The choice of mobility configuration depends on the application's nature, environmental conditions, and the specific requirements of the deployment. Each configuration comes with its unique challenges and opportunities for optimizing energy consumption [20]. The energy consumption of the sensors can be reduced due to a combination of factors including [9, 21, 22].

1. The overall count of sensor nodes in the network
2. The number of units used (the amount of secondary units added to the sensor node) and the required accuracy.

3. The energy consumption of a sensor node escalates as it performs more calculations, highlighting the direct relationship between increased processing demands and heightened power usage.

4. CR used between the sensor nodes. The duration of transmission and receiver (the interval of the sensor node in activity mode), where an increased communication range and the interval of the active node cause increased energy consumption.

5. Determining the duration required for a localization method to estimate the positions of all nodes in the network, along with assessing the storage space necessary for these computations, becomes increasingly critical as algorithmic complexity rises, consequently affecting energy consumption. Each sensor node has a battery as its independent power supply. The node will be turned off if this battery is damaged because it only offers a limited amount of energy. Additionally, in some WSN applications, it might be challenging to replace or recharge the battery, especially if the sensor nodes are placed in difficult-to-reach locations. In this instance, managing energy consumption in WSNs is a major challenge. As a result, the lifespan of the entire network will be prolonged by the nodes' effective use of power [23, 24]. Depending on whether or not the sensor contains GPS, it is categorized into three basic types.

### 2.2.2 Node Role in Localization

In the context of localization within WSNs, nodes assume distinct roles:

1. **Anchor Node (AN):** Also known as beacon nodes, anchor nodes possess known locations, either through GPS or pre-established coordinates. They play a pivotal role in aiding unknown nodes in determining their positions [25].
2. **Unknown Node (UN):** Unknown nodes lack predetermined positions and rely on anchor nodes to calculate their locations [26].
3. **Reference Node (RN):** After determining their positions, unknown nodes can transition into reference nodes. They broadcast their locations to neighboring nodes, aiding in the localization process [27].

### 2.3 Localization in WSNs

Localization, a core task within WSNs, entails determining the positions of nodes that lack site awareness. Given the increasing demand for WSNs across diverse applications, accurately pinpointing node locations becomes crucial. For a detailed explanation, the process of locating unknown node sensors or nodes that are unaware of their positions in a WSN is known as localization [28]. These days, WSNs are in demand because of their underlying applications. Finding the precise placement of the nodes is crucial because they are dispersed around the area at random. The sensor's main issues, which include limited cost and energy, prevent the location of all sensor nodes from being stored. There are numerous applications where knowing where each node is needed is essential. Therefore, one of the key problems for research is determining where the nodes are [29, 30].

Given the remarkable progress in wired and wireless communications and the widespread use of handheld devices, accurate positioning and location estimation of targets, whether they are mobile or fixed nodes, have become essential. Numerous customers, application developers, and service providers rely on precise location information to offer various services effectively and allocate resources efficiently. Identifying and correlating gathered data, addressing nodes, managing queries for nodes situated within a specified area, assessing node density and coverage, generating energy maps, implementing geographic routing, and tracking objects are among the factors that enhance the importance of localization in WSNs. These aspects, along with additional factors, establish localization systems as a crucial technology for establishing and operating [31].

Nowadays, many practical applications are becoming absolutely dependent on location awareness [25]. Many WSN applications, including environmental monitoring, temperature detection, and emergency rescue, heavily rely on the target's position awareness.

Both "active" and "passive" localization issues exist, depending on the type of target. Most of the time, active localization—localization performed by the target itself using range measurements—is possible. The targets, however, can only reflect or scatter the signals from the transmitter to the receivers in particular situations, such as tracking harmful targets and home crime prevention. The so-called passive localization is this [32]. Network, depending on the position data of a select few particular sensors and their inter-measurements in the network, such as connectivity, time difference of arrival, distance, and angle of arrival. The previous localization information sensors are known as anchors or references, and their locations can be determined

by putting anchors at locations with known coordinates or using GPS [26]. It's not always best to attach a GPS receiver to each node due to factors including cost, power availability, accessibility, accuracy, and sensor size, which is now the size of a small coin [27]. Therefore, one method utilized to determine the location of sensor nodes for localization is GPS. But in reality, using this technology is expensive, and one of its drawbacks is that it only functions outdoors [33].

Due to obstructions from trees or other physical structures, as well as being outside the range of cellular base stations, wireless sensor nodes may be situated in environments where it is impossible for them to receive wireless signals from satellites.

Therefore, current methods of estimating geographic location, including using GPS or cellular location services, are too expensive for WSNs. Consequently, there has been a great deal of study into the creation and localization of inexpensive sensor techniques that satisfy application requirements while operating within the hardware limitations of WSNs [34]. For these reasons, a huge set of algorithms has been proposed to solve the problem of node localization in the network by using a small set of GPS nodes that will help the rest of the nodes estimate their location in the network. As detecting the goal is crucial for military applications, data tagging, and many remote monitoring applications.

### 2.3.1 Applications of WSNs

Wireless Sensor Networks find applications across diverse domains, including [1, 35]:

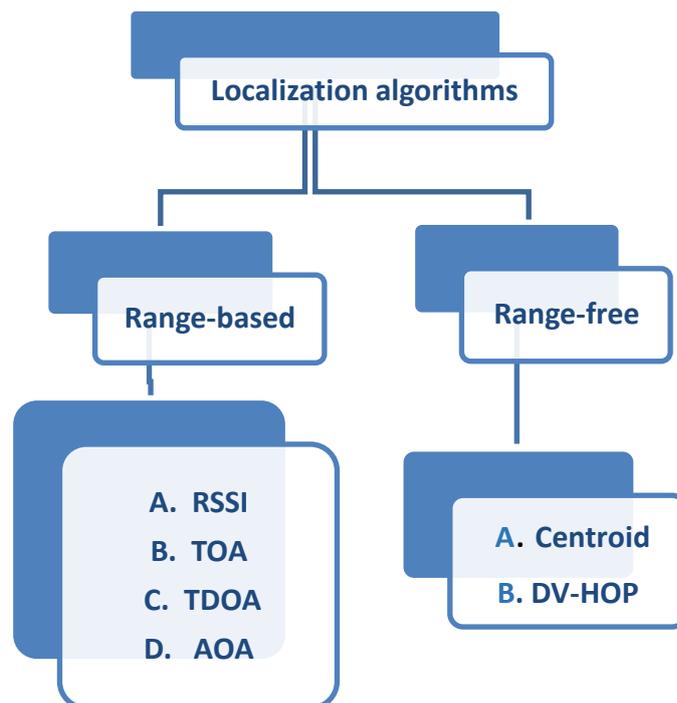
**1. *Military Applications:*** WSNs support military deployments for battlefield monitoring, smart missile system guidance, and threat detection. Literary, One of the applications of WSN is military deployment. It was developed to monitor battlefields and guide smart missile systems. It also aims to detect attacks or weapons.

**2. *Medical Applications:*** Sensor devices aid in patient diagnosis and monitoring, facilitating remote patient care and long-term health tracking. Sensors play a crucial role in the diagnosis and monitoring of patients in the medical field. Patients can have small sensor devices connected to them to track physiological indicators like heart rate and blood pressure. The BS receives the information received from the sensor nodes, which allows the doctor to quickly assess the patient's conditions and administer medication. This can help doctors monitor patients over an extended period, especially the elderly.

**3. *Environmental Monitoring:*** WSNs contribute to monitoring natural phenomena such as volcanoes, oceans, glaciers, and forests. They are instrumental in landslide detection systems and environmental data collection. In other word, applications of environmental sensor networks include those for sensing volcanoes, oceans, glaciers, and forests. These nodes contain sensors for both temperature and humidity. A landslide detection system equipped with WSNs can detect subtle soil movements or changes in soil properties before or during a landslide. These systems help collect information that can be used to prevent the occurrence of such natural phenomena

### 2.3.2 Classification of Localization Algorithms

Localization technology has sparked a significant wave of research, resulting in the development of a multitude of techniques aimed at accurately determining the positions of nodes WSNs. These various methodologies can be broadly categorized into two main groups: range-free approaches and range-based techniques [36], as illustrated in detail in Figure 2.2. This diversification of localization methods underscores the ongoing efforts to enhance the accuracy and efficiency of WSNs, catering to a wide array of applications and deployment scenarios[37].



**Figure 2.2 Classification of Localization Algorithms for Sensor Nodes[38]**

### 2.3.2.1 Range-Free Algorithms

Range-free algorithms, including centroid and DV-Hop methods, rely on nearby anchor nodes to determine node locations. While these methods are less accurate than range-based approaches. Notable range-free systems employ hop count-based data for position estimation. Although less accurate than range-based approaches, they don't require any additional hardware and use less energy [34]. Most range-free localization systems calculate the position primarily using hop count-based data. Innovative methods of this kind include Centroid and DV-Hop [17].

#### *A- Centroid*

Centroid localization is suitable when a sensor node has at least three nearby anchor nodes. It computes the node's estimated location as the centroid of its neighboring anchors. Centroid's accuracy is contingent on anchor distribution regularity. Centroid is meant for node sensors with no less than three nearby node anchors. Consider that all nodes have an equal communication range and that the sensor node  $N$  has three neighbor anchors,  $A_1$ ,  $A_2$ , and  $A_3$ , with the coordinates  $(x_1, y_1)$ ,  $(x_2, y_2)$ , and  $(x_3, y_3)$ . According to the Centroid principle, the estimated location is the  $N$  centroid, the center of the anchors.  $(X_{\text{centroid}}, Y_{\text{centroid}}) = ((x_1 + x_2 + x_3)/3, (y_1 + y_2 + y_3)/3)$  can be used to compute the position of  $N_{\text{centroid}}$ , denoted as  $(X_{\text{centroid}}, Y_{\text{centroid}})$ . When the distribution of anchors is regular, the centroid can achieve pretty high accuracy with very minimal communication and computation costs. However, the projected position produced from the Centroid technique will be incorrect if the distribution of anchors is not uniform [21].

In Figure (2.3), assuming that the unknown UN1 node is related to the anchor nodes (AN1, AN2, AN3, AN4), its coordinates are used to calculate the location of the node, as in equation (2.1). The study of the Weighted Centroid Localization Algorithm Based on RSS [39]:

$$UN_j(x_j, y_j) = \left( \frac{\sum_i^k x_i}{k}, \frac{\sum_i^k y_i}{k} \right) \quad (2.1)$$

Where  $UN_j$  is an unknown node,  $(x_j, y_j)$  is the coordinate of  $UN_j$ ,  $k$  is the number of A connected with UN, and  $(x_i, y_i)$  is the coordinate of AN.

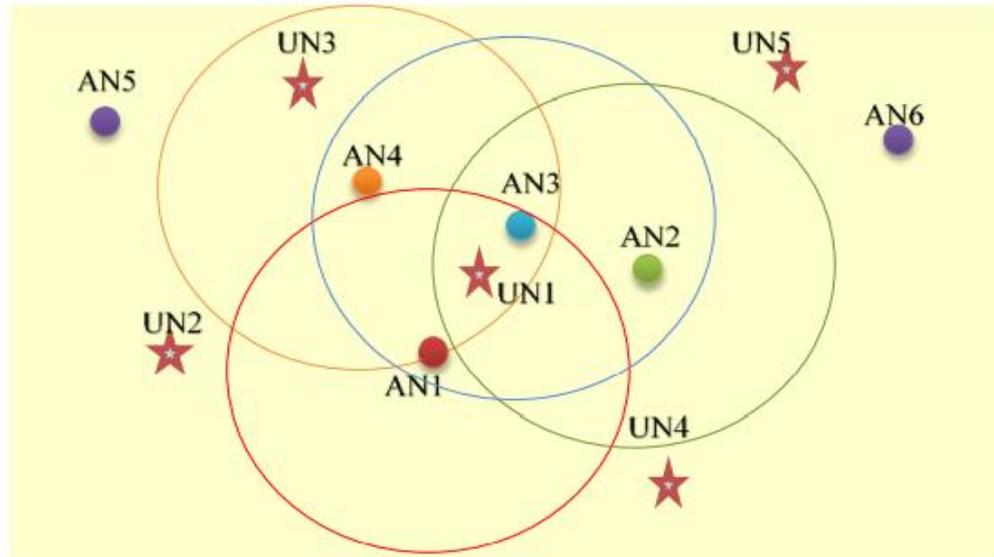


Figure 2.3: The Principle Diagram of Centroid Method[39]

### ***B- DV-Hop***

DV-Hop is a popular range-free algorithm known for its simplicity and energy-efficiency. It can estimate the positions of nodes with fewer than three nearby anchor nodes. DV-Hop operates in several phases, involving anchor node broadcasts, hop size determination, and trilateration. In sum, one of the most popular range-free methods is the DV-Hop localization algorithm, since it is simple to develop and uses

little power and money. The majority of localization strategies are effective for estimating the position of unknown nodes that have a minimum of 3 nearby anchor nodes [40-42]. However, DV-Hop localization can also be used for neighbors with fewer than three anchor nodes. The steps for DV-Hop localization of unknown nodes are as follows [43]:

- **The first stage** involves anchor nodes broadcasting a packet with their coordinates throughout the network. The value of the number of hop was originally set to 0. Every hop while broadcasting causes the number of hop value of the packets to rise by 1. This procedure ensures that all of the network's sensor nodes receive the minimal hop count.
- **The second stage** determines the hop size for each anchor node as follows:

$$hop_{size} = \frac{\sum_{p \neq m}^m \sqrt{(x_p - x_m)^2 + (y_p - y_m)^2}}{\sum_{p \neq m}^m h_{pm}} \quad (2.2)$$

$(x_m, y_m)$  is the position of anchor node,  $(x_p, y_p)$ ,  $\forall p \in [1, M]$  and  $p \neq m$ , are the positions of other anchor nodes, and  $h_{pm}$  denotes the minimum number of hop count between anchor  $p$  and  $m$ .

Calculations are used to determine the distances between unknown nodes and anchor nodes.

$$d_{ua} = Hop_{size} * h_{pu} \quad (2.3)$$

Where  $h_{pu}$  is the number of hop counts between anchor  $p$  and unknown node  $u$ .

- **The Third Stage:** Unknown nodes employ the trilateration approach to approximate their location in the third phase. Let  $(x, y)$  represent the position of the anchor node and  $(x_p, y_p)$  represent the

location of the unknown node. The equation states how far apart these nodes are from one another.

$$d_p = \sqrt{(x_p - x)^2 + (y_p - y)^2} \quad (2.4)$$

### 2.3.2.2 Range-Based Algorithms

Range-based techniques rely on distance or angle information between nodes for localization. While they offer higher accuracy, they entail greater hardware and energy costs. Additionally, RSSI has far less hardware than some other range-based distance estimation approaches and has a higher accuracy rate. The range-based localization approach estimates node locations using information on the distance or angle between various nodes. Although the range-based method is more accurate, it has the disadvantage of requiring more technology and using more energy [43].

Four fundamental range-based techniques include Time of Arrival (TOA), Time Difference of Arrival (TDOA), Angle of Arrival (AOA), and Received Signal Strength Indicator (RSSI).

#### A- Received Signal Strength Indicator (RSSI)

RSSI-based methods estimate distance by measuring the attenuation of radio signals with increasing distance. These methods are less accurate due to signal fluctuations caused by environmental factors and interference. The most basic method of estimating distance from the range-based strategy is signal strength. There are numerous varieties of RSSI signals, including Bluetooth signals, Wi-Fi, RF, and ZigBee. The communication distance, accuracy, cost, and power consumption of each of these types vary [44].

The idea behind range-based approaches based on RSSI is that the radio signal consistently weakens with increasing distance. Without the need for extra hardware or data transmission, these algorithms estimate the distance between the anchor node and the unknown target node based on the attenuation degree of the received signals. Implementation costs are modest, making realization simple. As a result, these methods are now the ones that in WSNs employ the most frequently [45]. The signal strength is commonly measured in dBm (decibels in reference to one mill watt) or watts [45]. An anchor node generates a signal to begin the operation, which is picked up by the transceiver circuitry and sent to the (RSSI) to measure its strength. The following equation can be used to determine the reading from the RSS of nodes  $i$  and  $j$  at time  $t$ :

$$p_R^{ij}(t) = P_T^i - 10\eta \log(d_{ij}) + X_{ij}(t) \quad (2.5)$$

where  $d_{ij}$  is the distance between the two nodes,  $\eta$  is the attenuation constant,  $P_T^i$  is a constant resulting from the transmitted power and antenna gains of the sensor nodes, and  $X_{ij}(t)$  is the uncertainty factor brought on by multi-path and shadowing [46].

$$RSSI_d(dBm) = RSSI_{d_0}(dBm) - 10_{n \log} \frac{d}{d_0} + x_\sigma \quad (2.6)$$

Where:  $RSSI_d$  is the power received signal by UN.  $RSSI_{d_0}$ , which is typically 1m between an anchor and a sensor, is the signal power received by UN at reference distance  $d_0$ ,  $d$  is the distance from receiver node to the sender node. The path loss constant,  $n$ , has a value between 2 and 5 and is represented by the relationship  $10 \log d/d_0$ . As a Gaussian random variable with  $\sigma$  value between 4 and 10,  $x_\sigma$  represents the random variation in RSSI. The environment-specific values of  $n$  and  $\sigma$  are determined. RSSI suffers from some drawbacks thus, the possibility of

inaccurate distance estimates due to multipath reflections, non-line-of-sight circumstances, and other shadowing effects.

Methods that combine RSSI and other metrics can produce accurate position estimates. Though RSSI approaches are unreliable and imprecise because of non-uniform propagation settings [47].

## B. Time of Arrival (TOA)

TOA is one of the range-based algorithms having another name, which is Time-Of-Fight TOF. This method is used to solve the problem of relying on radio signals in estimating the distance (the attenuation and noise experienced by the radio signal). Calculating the distance between the source AN and target UN nodes depends on time. Sending a signal in  $S_{time}$  from the source node to the target node is what this method entails. The signal is returned to the source node by the target node in  $A_{time}$  after a delay. The method employs at the time of arrival and the delay in returning the signal in determining the distance; the signal need not be returned at the exact same time [48, 49]. The distance  $D$  is estimated based on the speed of the signal  $C$  and the difference between the start time  $S_{time}$  and the arrival time  $A_{time}$  from the sender node to the received node. As in equation (2.7) [50].

$$D = C \times (A_{time} - S_{time}) \quad (2.7)$$

This method is characterized by its good accuracy in calculating the distance, it is widely used in indoor environments such as office and home. However, the problem with this method is that it increases cost and complexity as it requires time synchronization between source and target. In addition to its problems related to the speed of light and the speed of diffusion [48, 49, 51] .

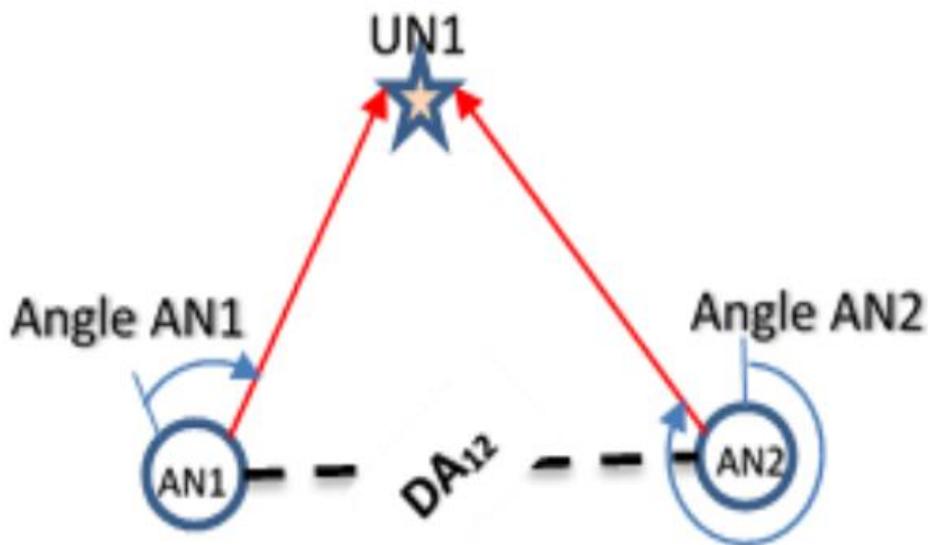
### C. Time Difference of Arrival (TDOA)

This method of range algorithms is very similar to the previous method. It depends on time when calculating the distance between the source node (AN) and the target node (UN). The advantages of this technology are high localization accuracy and the repair of previous technology problems. Therefore, it has the advantage of not requiring synchronization at the time between the source and the target and its dependence on binary signals instead of one. One of the uses of this method is GPS. The steps of this method are to send a signal from the source node to the target node in  $S_{time}$ . After a delay, the target node returns the signal to the source node in  $A_{time}$ . It is not required that the signal be returned at the same moment, and the method is used at the time of arrival and the delay in returning the signal to estimate the distance. To conclude, Time Of Arrival (TOA) and Time Difference Of Arrival (TDOA), TOA measures the time taken for a signal to travel from the source to the destination. TDOA compares the time of arrival of signals at multiple anchor nodes to estimate distances. It is not required that the signal be returned at the same moment, and the method is used at the time of arrival and the delay in returning the signal to estimate the distance[48].

### D- Angle of Arrival (AOA)

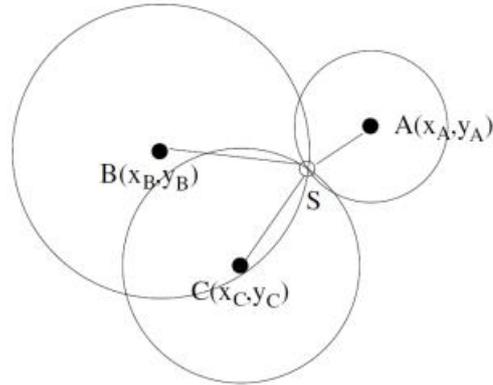
In the AOA method, the distance between the transmitter and the receiver is found, depending on the angle and direction of the signal's arrival to the unknown node. The anchor nodes transmit their specified location by GPS or by manual method. By using ANs with directional antennas or directional matrices, to determine the distance between ANs and UN depending on the angles instead of the signal strength. The UN uses two angle information and a distance between two anchor nodes to

estimate its location. Figure (2.4) shown the principle diagram of AOA method. Assuming that UN1 is a sensor node in the AN2 communication range, AN1 needs to know the angles between it and AN1, AN2, and the distance  $DA_{12}$  to estimate its location. This method has the advantage of not requiring synchronization and depends on at least two signals in determining the location. However, the obstacles to this method are in high cost and complex calculations. In addition to being affected by wind and fading, which causes errors in estimating the position [48, 49].



**Figure 2.4: The Principle Diagram of AOA Method**

One of the most recognized localization techniques in wireless sensor networks is Trilateration this technique determines a node's location at the intersection of three circles made up of three anchor nodes, constructed based on measurements of the distances between the node's neighbors. According to Figure 2.5, the circle's diameter is equal to the measured distance [46].



**Figure 2.5: Trilateration technique [40]**

Figure 2.6 illustrates how the points of intersection are found by the following equations:

The centers of both circles,  $C_1(x_1, y_1)$  and  $C_2(x_2, y_2)$ , are determined by the formula 2.8

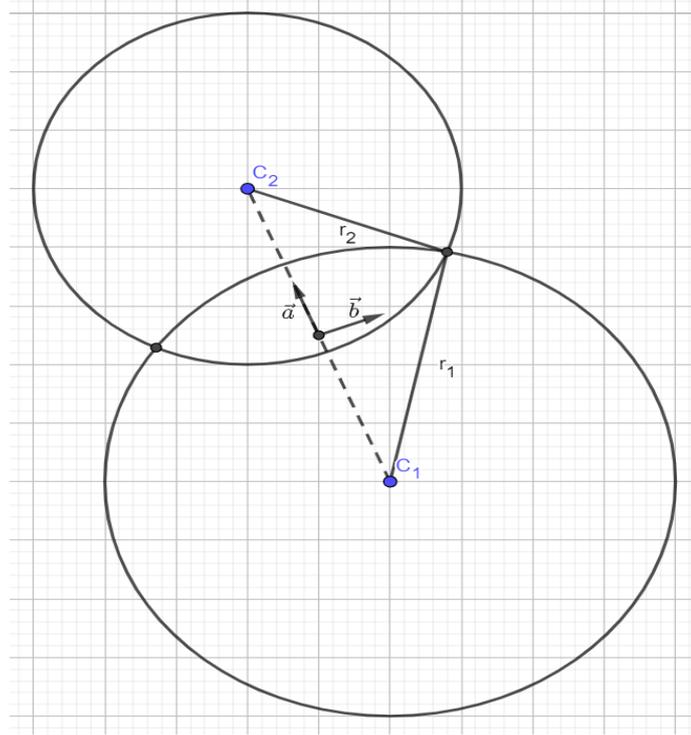
$$\left( \frac{x_1 + x_2}{2}, \frac{y_1 + y_2}{2} \right) \quad (2.8)$$

Equation 2.9 provides the distance between the circle's centers.

$$R = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (2.9)$$

These orthogonal vectors are suitable for consideration by equation 2.10.

$$\vec{a} = \left( \frac{x_2 - x_1}{R} \right), \quad \vec{b} = \left( \frac{y_2 - y_1}{R} \right) \quad (2.10)$$



**Figure 2.6 Illustrates The Points of Intersection for Two Circles**

In the  $(\vec{a}, \vec{b})$  plane we get the equations (2.11), (2.12):

$$(a + R/2)^2 + b^2 = r_1^2, (a - R/2)^2 + b^2 = r_2^2 \quad (2.11)$$

$$a = \frac{r_1^2 - r_2^2}{2R}, b = \pm \sqrt{\frac{r_1^2 + r_2^2}{2} - \frac{(r_1^2 - r_2^2)^2}{4R^2} - \frac{R^2}{4}} \quad (2.12)$$

The equations 2.13 of the points of intersection

$$\begin{aligned} x &= \frac{1}{2}(x_1 + x_2) + \frac{r_1^2 - r_2^2}{2R^2}(x_1 - x_2) \pm \frac{1}{2} \sqrt{2 \frac{r_1^2 + r_2^2}{R^2} - \frac{(r_1^2 - r_2^2)^2}{R^4} - 1} (x_1 - x_2) \\ y &= \frac{1}{2}(y_1 + y_2) + \frac{r_1^2 - r_2^2}{2R^2}(y_1 - y_2) \pm \frac{1}{2} \sqrt{2 \frac{r_1^2 + r_2^2}{R^2} - \frac{(r_1^2 - r_2^2)^2}{R^4} - 1} (y_1 - y_2) \end{aligned} \quad (2.13)$$

Here,  $\mathbf{R}$  represents the distance between the circle centers.

## 2.4 Performance Evaluation

Performance measures have been relied on in terms of localization accuracy and energy consumed from the sensor nodes to determine the effectiveness of the suggested algorithm. Several performance metrics help evaluate localization accuracy and efficiency:

### 2.4.1 Localization Accuracy

Localization accuracy is one of the most important performance criteria for localization methods, as estimating the location of sensors in the network with high accuracy is the primary goal of a large group of researchers. The accuracy of the model is evaluated in the proposed algorithm based on the average localization error of the sensor nodes. The localization error is calculated using the Euclidean distance equation, which depends on finding the difference between the actual-position of the sensor and the position detected as in equation (2.14)[52, 53].

$$\mathbf{Error}_{(i)} = \sqrt{(x_i - u_i)^2 + (y_i - v_i)^2} \quad (2.14)$$

Where  $(x_i, y_i)$  are the node is actual locations and  $(u_i, v_i)$  are its estimated positions. When there are N unknown nodes, the average localization error,  $\mathbf{error}_{(avg)}$  is given as (2.15)[52, 53].

$$\mathbf{error}_{avg} = (\sum_{i=1}^N \mathbf{error}_{(i)}) / N \quad (2.15)$$

Where  $\mathbf{error}_{avg}$  the average localization error, N is the number of the unknown nodes except those nodes whose coordinates cannot be obtained.

### 2.4.2 Energy Consumption

Energy consumption is among the most crucial indicators for determining the age of the sensors, so finding a way to estimate the locations of the sensed nodes with the fewest number of connections with the anchor nodes (efficient energy consumption) is an important primary goal in many research [12]. In our proposed method, only the energy consumed by the sensors has been considered, without paying attention to the power consumed by the anchor node. Where the equation (2.16) is used to calculate the E for each message received by the sensor node [12].

$$E_{\text{rec}} = P_{\text{rec}} \times \frac{P_{\text{size}}}{\text{data-rate}} \quad 2.16$$

$E_{\text{rec}}$  is the energy consumed for per receiving message from anchor node, Where  $P_{\text{rec}}$  is the received power, and  $P_{\text{size}}$  the size of the package received from the anchor nodes. In evaluating the performance of our proposed algorithm, the data rate and  $P_{\text{rec}}$  values were used depending on [12]. Where  $P_{\text{rec}}$  is (15.5 mA) and data-rate is (125 kbps). The  $P_{\text{size}}$  value in our model is 80 bit only because the AN beacon message content only coordinate (x, y) and ID.

The required power consumption for localization sensor nodes in the network is calculated by equation (2.17) [12]:

$$E_{\text{node}} = M_{\text{rec}} \times E_{\text{rec}} \quad 2.17$$

Where  $M_{\text{rec}}$  represents the overall count of received messages by that sensor node, and  $E_{\text{node}}$  is the power consumption from sensor node.

We find the energy use for a nodes, where  $M_{\text{rec}}$  the total number of messages the node has every received. The calculation for the average energy consumption is then as follows as (2. 18):

$$\overline{E_{\text{node}}} = \frac{\sum_{i=1}^N E_{\text{node}i}}{N} \quad (2.18)$$

The following [12] employs a formula to calculate the energy usage for nodes the energy used to establish connections with the deployed nodes,  $E_{send}$  (2.19) and (2.20).

$$E_{send} = p_{send} \quad (2.19)$$

$$E_{send} = M_{trans} \times E_{trans} \quad (2.20)$$

Where  $M_{trans}$  and  $E_{trans}$ , the number of messages transmitted and the amount of energy used to send each message, respectively. To calculate energy for all network, we first need energy consumption to discover the neighbors by equation (2.21)

$$E_{det} = N \times E_{send} + 2M \times E_{rec} \quad (2.21)$$

Where  $E_{det}$  represent the energy detection and  $N$  and  $M$ , the number of sensors and the number of links in the network, respectively.

The second part, the energy needed to route messages to the Sink, is calculated based on the network topology, and each graph has its own routing energy.

## 2.5 Summary

WSN is a collection of sensors that are connected to sense their surroundings. The sensor nodes are characterized by not including location information. Localization is the process of estimating node locations. For sensor node localization, several methods have been suggested. The two main categories are range-free and range-based. Range-free methods are cheap and easy and do not require hardware, but the accuracy of node locations is poor. While range-based methods are good at estimating the position, they cost a lot, and more hardware is needed to estimate the location. The performance of the localization of the sensor nodes is evaluated using the accuracy, the average localization error, and how much energy the sensor node uses.

## *Chapter Three*

### *The Proposed System*

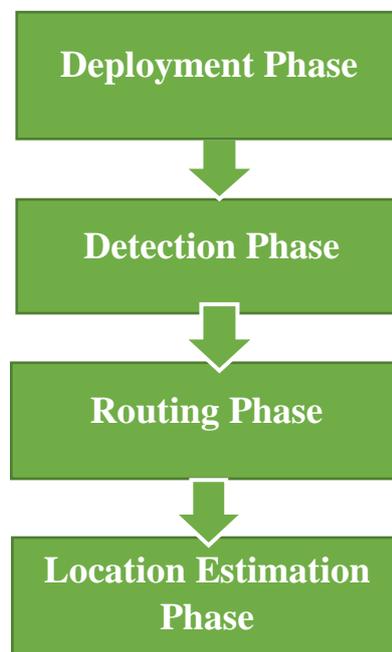
#### **3.1 Introduction**

The steps taken to achieve the main objectives of this thesis are discussed in this chapter. This includes developing a strategy for estimating the locations of the deployed sensor nodes in the target field. First, the structure of this four-phase system is described, after which each phase is discussed in detail. This chapter is organized into four sections, including the introduction. Implementation is covered in Section Two. The suggested algorithm, Graph-Based Localization Estimation GBLE, is presented in Section Three. Summary of the chapter in Section Four.

#### **3.2 The Proposed System**

The proposed range-based algorithm leverages the Received Signal Strength Indication (RSSI) principle and relies on the presence of three strategically positioned static anchor nodes. This section presents an innovative approach for localizing each unknown node within the target field. Within the network, sensor nodes operate in three distinct states. Initially, upon deployment, they assume the listening mode. Upon receiving a message, nodes transition into the active mode. Finally, when forwarding the message to neighboring nodes, they enter the routing state. The design of this proposed model is underpinned by a set of carefully considered factors, the specifics of which depend on the model's construction. Notably, a set of Unknown Nodes (UNs) is uniformly deployed across a predefined area bounded by coordinates (W, H), forming a foundational basis for this localization endeavor. Within a predefined

field of specified dimensions, our sensor network deploys two distinct types of sensor nodes. The first category consists of the unknown nodes, equipped with essential components including sensing capabilities, power resources, processing units, and communication functionalities. Alongside them, we have anchor nodes, which boast a more comprehensive suite of features. These anchor nodes not only possess sensing, power, and processing capabilities but also include advanced communication functionalities, GPS technology for precise location determination, and a power generator to sustain their energy needs. This combination of sensor node types forms the foundation of our network, allowing for robust and accurate data collection and localization capabilities. Figure 3.1 shows the phases of the proposed model.

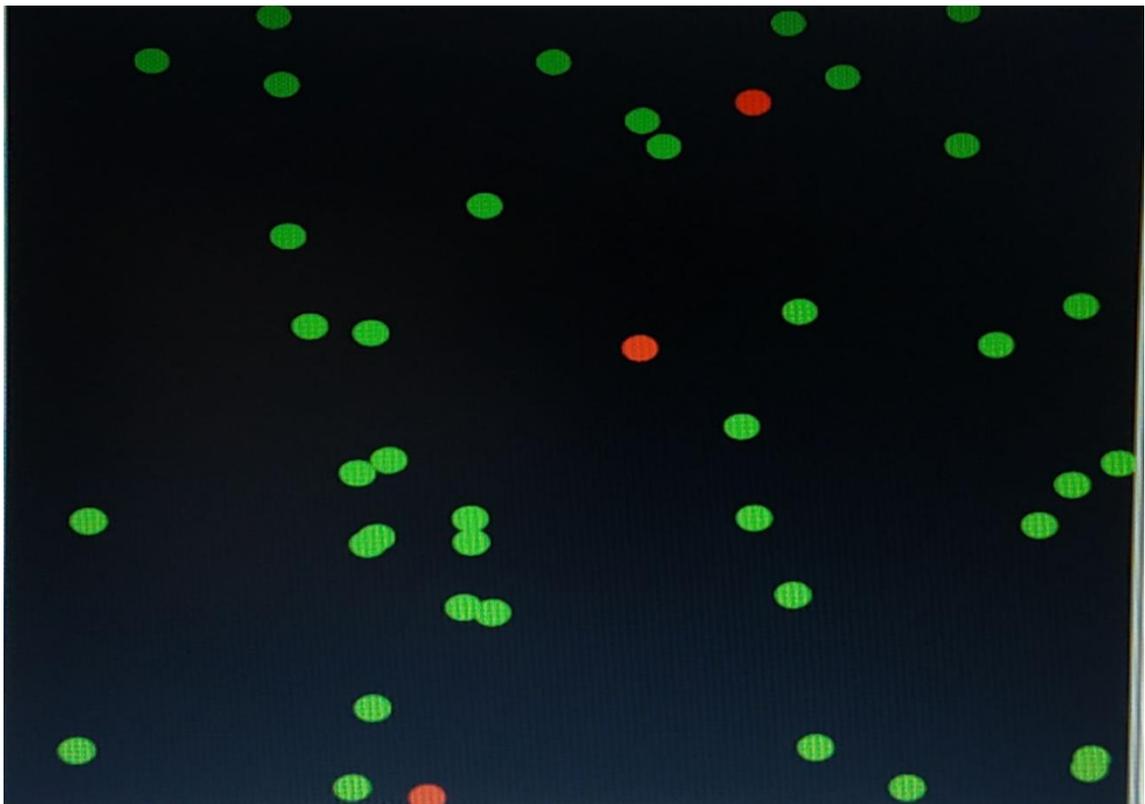


**Figure 3.1: Phases of The Proposed Model**

The phases of the suggested method are shown below:

### 3.2.1 Deployment Phase

Distributing unknown nodes UNs uniformly at random in a specific area ( $W \times H$ )  $m^2$ . It is necessary to deploy three static anchor nodes ANs having location information. The sink node should be represented by one of these ANs, which should be placed in the area center. As shown in the Figure 3.2 , the anchor nodes are represented in red and the unknown nodes are represented in green.



**Figure 3.2: Deployment Phase**

### 3.2.2 Detection Phase

- SINK node start broadcast hello messages and other nodes in listening mode.
- A node  $n_i$  start in listening mode.
- When  $n_i$  received a message from another neighbors  $n_j$  being in active mode then
  - ✓ Computes its distance  $d_{ij}$  ( $n_i$  ,  $n_j$ ) based on RSSI.
  - ✓ Add  $n_i$  ,  $d_{ij}$  to local neighbor list.
  - ✓ Obtains the path length  $L_j$  ( $n_j$ , SINK) from the received message.
  - ✓ Compute new Path length  $L_i = d_{ij} + L_j$  .
  - ✓ set next hop  $n_j$  when  $\delta_j: \min \delta_j (n_j ,SINK)$  for  $\forall_j = 1$  to  $\text{deg}(n_i)$ .
- Set  $n_i$  mode to active and broadcast its ID and  $\delta_i$  .

In this phase, all nodes detect neighbors and short paths to the sink node.

### 3.2.3 Routing Phase

The main goal of the routing process is to achieve efficient and reliable communication between all devices participating in the wireless network by determining the optimal path for data transmission.

- The node sends its neighbors list to its next hop once.
- If a node receives a message from any of its neighbors, it re-sends it to the next hop.

When all messages arrive, the sink creates an adjacency matrix for the network.

### 3.2.4 Location Estimation Phase

The unknown node uses the GBLE algorithm to calculate its location, which will be explained later in this chapter. After completing the use of the GBLE algorithm to localize the UNs in the network. The performance of the model is evaluated based on the performance evaluation metrics mentioned in Chapter two.

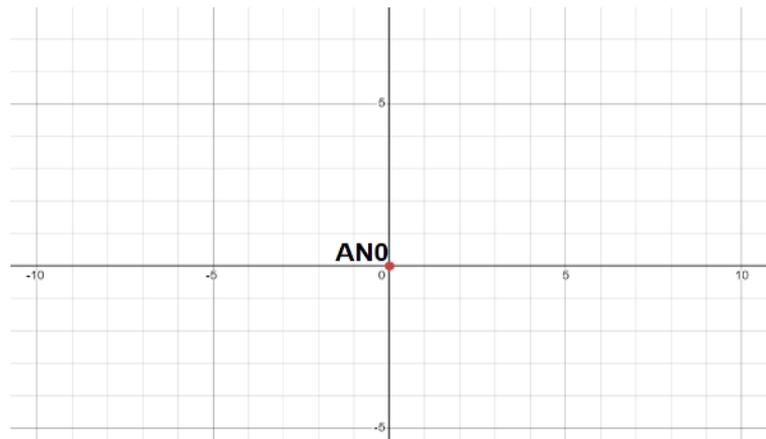
### 3.3 Graph Based Localization Estimation (GBLE)

This process is done by the sink, which is the first anchor. Using the adjacency matrix aggregated in the sink, a corresponding graph is created, and the location of each node is estimated using GBLE. The estimation process can be explained in detail in the following steps:

**1:** The anchor node  $AN_0(x_0, y_0)$  considered the center of the graph being created, will be the node around which the graph rotates.

**Example:** Suppose the selected node is located at point  $(x = 0, y = 0)$

Figure 3.3 illustrates this.



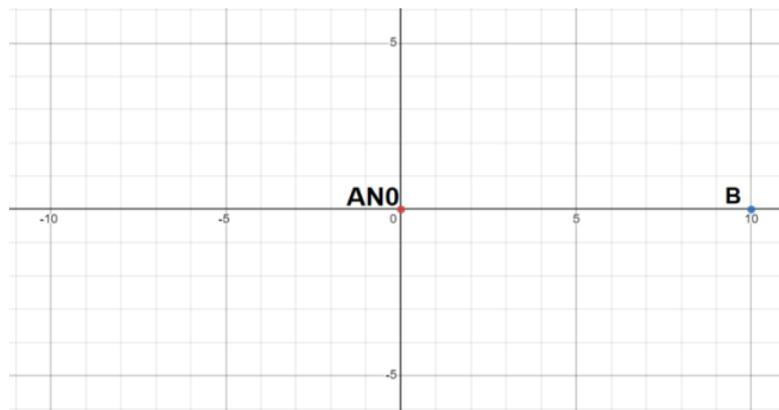
**Figure 3.3:  $AN_0$  Location**

**2:** Pick node **B** from the neighbor list of the selected anchor node  $AN_0$ .

**Example:** Suppose the distance is 10 m.

**3:** Assuming the angle of the node **B** is zero, making the location of node  $B(x_0 + \mathbf{dis}, y_0)$  where  $\mathbf{dis}$  is the distance between  $AN_0$  and **B**.

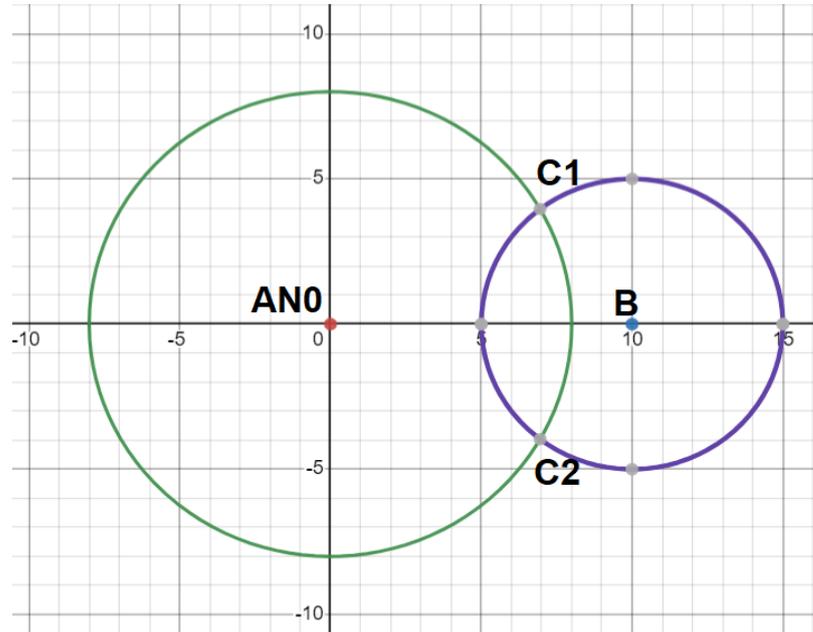
**Example:** the location of node **B** (10, 0). According to Figure 3.4



**Figure 3.4: Locations of  $AN_0$  and B**

**4:** Pick another node **C** that shares a link with both  $AN_0$  and **B**. Based on distances  $r_1$  and  $r_2$  there are two possible locations for node **C** this is based on circles intersections in equation 2.13. Where  $r_1$  is  $d(AN_0, C)$ ,  $r_2$  is  $d(B, C)$ ,  $R$  is distance between centers of circles.

**Example:**  $r_1 = 8$ , and  $r_2 = 5$ . The possible location of node **C1** (6.95, 3.96) and **C2** (6.95, -3.96) as shown in figure 3.5



**Figure 3.5: Possible Locations of Node C**

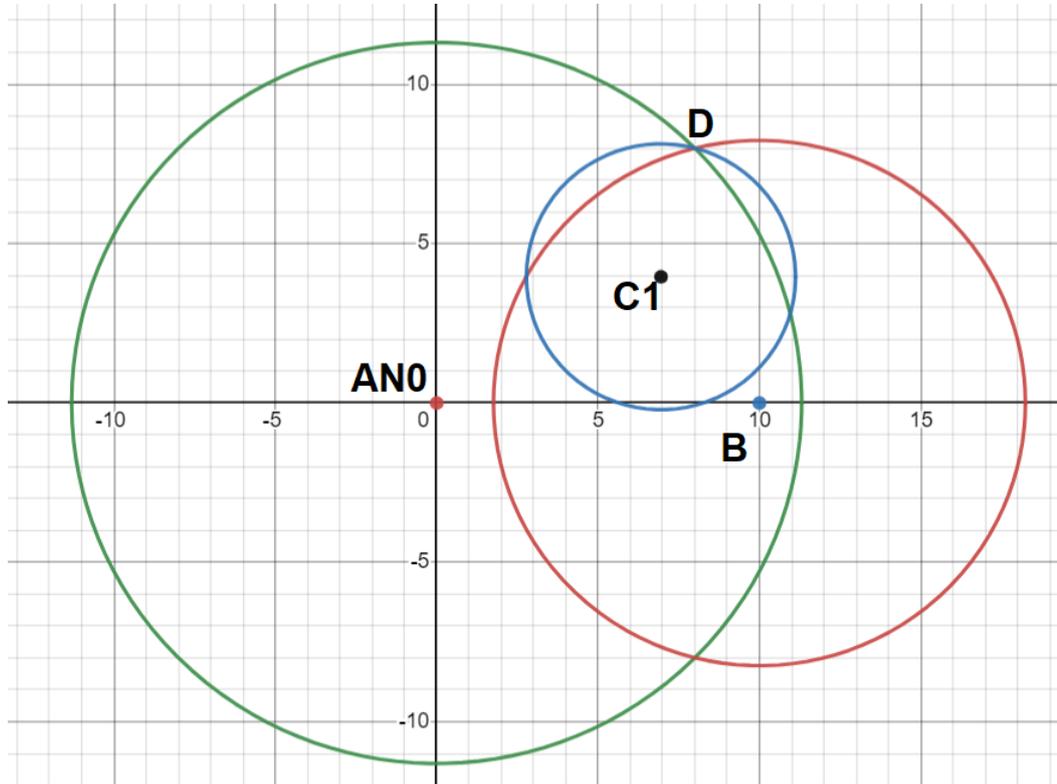
- 5:** For each possible location of node *C* do the following steps from **6** to **7**
- 6:** For each unknown node, *D*, which has three reference nodes, estimate its location and compute its location by the following sub-steps.
1. Get three shared reference nodes, for example ( $AN_0$ , **B**, **C1**)
  2. Compute distances to them using RSSI, for example ( $r_1 = 11.31$ ,  $r_2 = 8.246$ ,  $r_3 = 4.17$ ).
  3. Solve the three circle equations below to find the intersection, which represents node *D* the numbers in the equation are from the same example.

$$(x - 0)^2 + (y - 0)^2 = 11.31^2$$

$$(x - 10)^2 + (y - 0)^2 = 8.24^2$$

$$(x - 6.95)^2 + (y - 3.96)^2 = 4.17^2$$

After solve these equations, the location of node D is (8, 8) as shown in figure 3.6



**Figure 3.6: Calculations of Unknown Node**

**7:** After all nodes are known, rotate the graph around  $AN_0$  based on the following sub steps:

1. Calculate  $\theta_1$  between  $AN_0$  and second anchor  $AN_1$  (calculated) using the equation (3.6).

$$\theta_1 = \tan^{-1} \left( \frac{y_2 \text{ cal} - y_1}{x_2 \text{ cal} - x_1} \right) \quad (3.6)$$

2. Calculate  $\theta_2$  between  $AN_0$  and second anchor  $AN_1$  (real) based on following equation (3.7).

$$\theta_2 = \tan^{-1} \left( \frac{y_{2 \text{ real}} - y_1}{x_{2 \text{ real}} - x_1} \right) \quad (3.7)$$

3. Rotate every node around  $AN_0$  by equations (3.9) and (3.10) based on  $\Theta$  by equation (3.8).

$$\theta = \theta_2 - \theta_1 \quad (3.8)$$

$$x_2 = x_1 + R \times \cos(\theta) \quad (3.9)$$

$$y_2 = y_1 + R \times \sin(\theta) \quad (3.10)$$

**8:** If both the calculated and real locations of the third anchor  $AN_2$  is not equal, go to Step **5**; otherwise, end the algorithm and use the rotated graph as the final graph.

Algorithm (3.1) presents the GBLE algorithm for localizing UNs.

### Algorithm 3.1: GBLE

**Input :** An adjacency matrix

**Output :** Coordinates of UNs.

**Begin**

1.  $AN_0 \leftarrow (x_0, y_0)$
2.  $B \leftarrow (x_0 + \text{dis}, y_0)$
3.  $C \leftarrow (x, y)$
4. For each possible locations of C
5.     For each UNs has at least 3 reference nodes
6.         Compute: points of intersection  $(X_1, Y_1)$  as Eq. (2.13)
7.     End for
8.     Compute :  $\theta_1, \theta_2$  as Eq. (3.6) (3.7) respectively
9.     Compute: rotate angle as Eq.(3.8)
10.     Compute: $(X_2, Y_2)$  as Eq. (3.9) (3.10) respectively
11.     If  $(X_2, Y_2) = (X_1, Y_1)$
12.         Return coordinates of UNs
13.     Else
14.         go to step 4
15.     End if
16. End for
17. End

### 3.4 Summary

Depending on the algorithm employed, our Graph Based Localization Estimation GBLE relies on the presence of three anchor nodes to effectively localize the unknown nodes within the network. This localization process hinges on a fundamental principle: for accurate sensor node localization, the SINK (Sink node) must have access to a minimum of three known nodes associated with each unknown node within the network. As elucidated in the preceding chapters, the GBLE algorithm leverages Received Signal Strength Indicator (RSSI) values and the measurement of distances between nodes to estimate the positions of the unknown nodes. This process can be likened to the intersection of circles, where the circles represent the transmission ranges of anchor nodes, and the point of intersection signifies the approximate location of the unknown node. The intricacies of this algorithm's operation and the mathematics underpinning the intersection of these circles form the focal point of our investigation, shedding light on the precise methodology employed for sensor node localization in wireless sensor networks.

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## *Chapter Four*

### *Results and Discussions*

#### **4.1 Introduction**

We assess the GBLE algorithm performance regarding precision and energy consumption from the UNs, analyze the findings, and compare them to those obtained using alternative techniques. The proposed methodology yielded results characterized by enhanced precision in contrast to alternative strategies.

#### **4.2 Experimental Environment**

The model was implemented using simulation program. It is a wide virtual environment where sensors can be deployed. And the C# language was used to estimate the locations of the unknown nodes. The model was created using the NetLogo version 6.2.2 simulation tool. It is a simulation platform for several scientific disciplines, including physics, medicine, and mathematics, biology, and computer science.

#### **4.3 Parameter Setting**

The static anchor nodes were used to implement the GBLE algorithm. Utilizing the "NetLogo" environment [54] and C#, we evaluated the suggested algorithm's performance and compared its results using the average localization error and average energy consumption. The number of anchor node, the amount of unknown node, and communication range are among several variables that are used. An area of  $80 \times 80 \text{ m}^2$  is used for the GBLE algorithm simulation scenario. Three sets of the sensor nodes 70, 100, and 120 are uniformly distributed around this area at random. The

three sets of sensor nodes experimented with using two different communication ranges of RSSI: 35 m and 20 m. The summary of the parameter is shown in Table (4.1).

**Table 4.1: Simulation Parameters**

Parameters	Value
Network size	80 x 80 $m^2$
Number of Anchor Nodes (#ANs)	3
Number of Sensor Nodes (#UNs)	70, 100, 120
Communication Range (CR)	20 , 35 m
Packet size	80 bit
$P_{rec}$	15.5mA
Data-rate	125kbps

These are approximate numbers calculated through simulation, as shown in Table 4.2.

**Table 4.2: Describe Routing Energy**

#Sensors	Range	E routing
70	20	212
100	20	327
120	20	391
70	35	275
100	35	388
120	35	463

The minimum degree for each node should be 3 or greater, and this is based on the field area and CR between nodes. This determines the number of nodes to use. As shown in Table 4.3.

Table 4.3: Degree for each Sensor Nodes

# nodes	CR	Min degree	Max degree
40	15	0	9
	20	0	13
	25	3	11
	30	4	15
	35	5	17
50	10	0	5
	15	0	8
	20	2	15
	25	3	20
	30	4	27
	35	8	33
73	10	0	6
	15	2	11
	20	3	17
	25	4	26
	30	8	34
	35	14	43
103	10	0	7
	15	2	17
	20	5	25
	25	8	34
	30	15	48
	35	15	59
123	10	0	9
	15	3	20
	20	7	31
	25	9	42
	30	11	59
	35	21	77

## 4.4 Evaluation and Results

In order to determine the Effectiveness of the suggested method, we examined the model, considering the facets deliberated upon in chapter two. In the section below, the performance evaluation of the algorithm is reviewed and discussed using three static anchor nodes.

RSSI is represented as the Euclidean distance between pairs of nodes in the model; we find localization error for UNs set 70, 100, and 120 with different CR 20 m and 35 m. Figure 4.1 shows the relationship between CR and average localization error. Different experiments when CR are 20, and 35 m with UNs set at 70, 100, and 120 are conducted. The result shows that increasing the CR causes a decrease in the localization error for different set sizes of the UNs. The longer CR, the greater the number of connections between the nodes. This is the reason for increasing accuracy and reducing the average localization error.

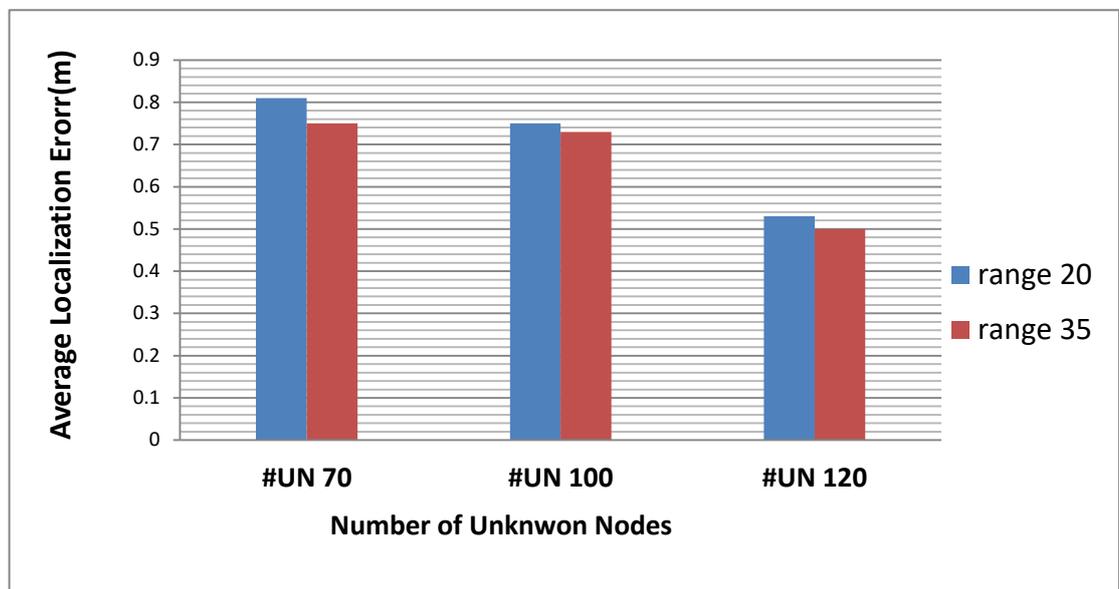
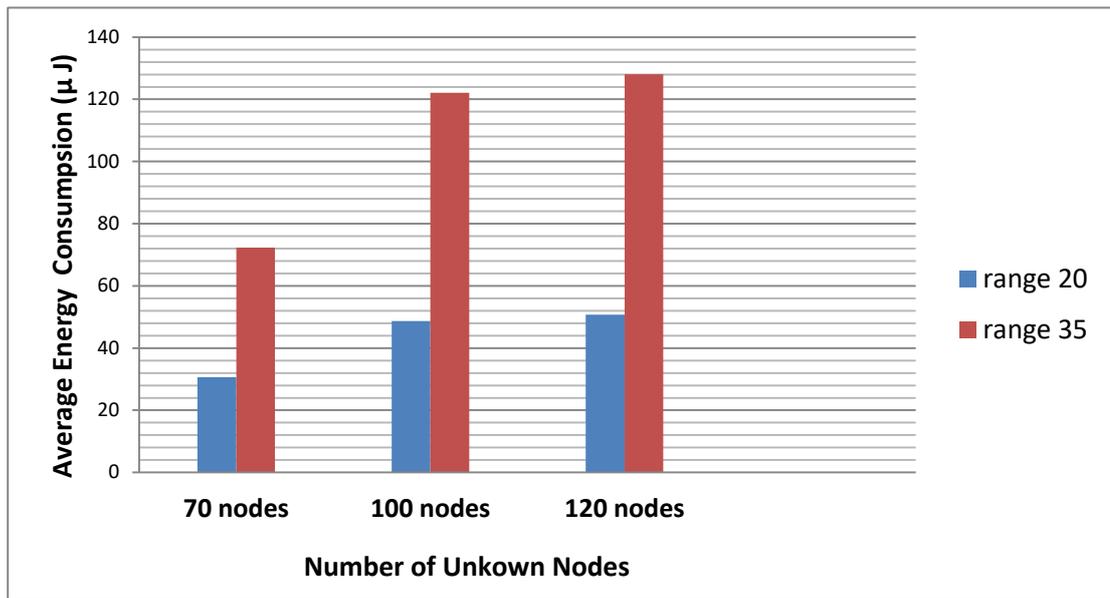


Figure 4.1 : Relationship between CR and Average Localization Error

Figure. 4.2 illustrates the relationship between CR and the average energy consumption of each sensor node. We used CR of 20, and 35 m, with nodes set to 70, 100, and 120. The result emphasizes that increasing the communication range increases the energy consumption of the network. The number of connections between nodes increases with a longer communication range. This is the reason why energy consumption has increased.



**Figure 4.2: Relationship between CR and Average Energy Consumption of The Sensor**

By using three anchor nodes, Table 4.4 shows the performance evaluation of the GBLE algorithm with different measures; it was explained in Chapter two. In this table, using different CR. It shows the minimum and maximum of the average localization error of experiments, the average localization error, and the average energy consumption of sensor nodes in the network and per sensor in the network. Depending on the result, choosing a large CR increases the accuracy of the position in the network, but its increases energy consumption, such as with CR 35 m. While using a small CR it will reduces the accuracy of the calculation of the sensor nodes positions in the network. However, cause a reduction in

energy consumption, such as when CR is 20 m. It can also be seen that, for each CR, the energy consumed by all sensors in the network increases with the number of sensors deployed in the network, while the average localization error decreases for each sensor. In addition, there is an effect of sensor node density with the accurate calculation of sensor node location.

**Table 4.4: The Performance Evaluation of GBLE Algorithm**

#UNs	Range (m)	Connections	$Error_{avg}$ (m)	Max Error	Min Error	Energy Consumption ( $\mu J$ )	
						Network	Sensor
70	20	370	0.81	1.31	0.13	2239.9	30.6
100	20	892	0.75	1.33	0.15	5023.6	48.7
120	20	1236	0.53	1.16	0.004	6196.14	50.7
70	35	931	0.75	1.33	0.06	5283.8	72.3
100	35	2404	0.73	1.26	0.11	12583.7	122.1
120	35	3096	0.50	1.003	0.06	15630.7	128.1

#### 4.5 Comparison with other Works

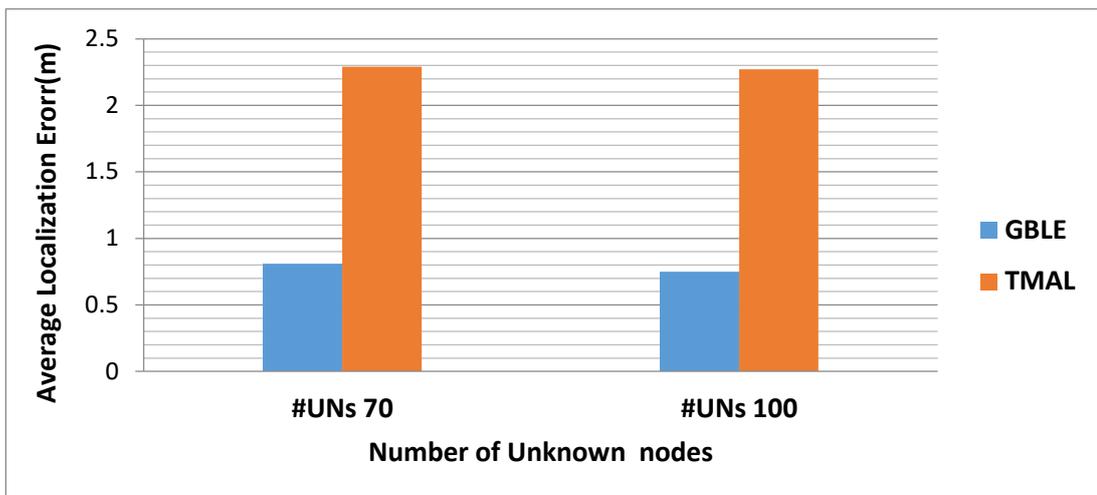
In this section, the performance results of the GBLE algorithm were compared with those of other algorithms. Three experiments were used from three different references. In the first experiment, the performance of the GBLE algorithm was compared with the TMAL algorithm, which was presented in [13]. We used localizing 70 and 100 UNs with CR 20 and 35 m from our proposed algorithm.

In the second experiment, the performance of the GBLE algorithm was compared to the UNL method [9], which used a total of UNs 100 sensor nodes and four anchor nodes. In the third experiment [12], we compared our method with the H-Curve method in terms of energy consumption,

based on the performance evaluation mentioned in Chapter two, and using a communication range of 20 m.

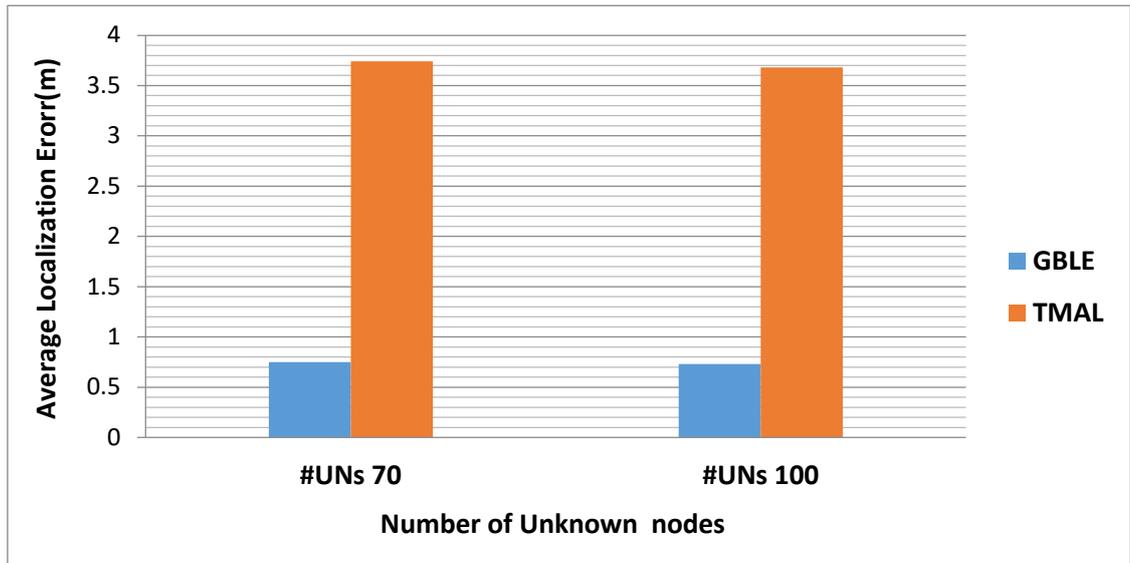
### A. Localization Error

To assess the effectiveness of the GBLE algorithm through the average of localization errors. Figures (4.3) and (4.4) show the average localization error of the proposed algorithm when three anchor nodes are used in the first comparison experiment [13]. Based on the results, the GBLE algorithm gave the best results compared to the TMAL algorithm, as it obtained an average localization error of 0.81 and 0.75 meters with a number of sensors of 70 and 100, respectively, and a CR of 20 m. While the CR is 35 m and we have the same number of sensor nodes, we achieved an average localization error of 0.75 and 0.73 m.



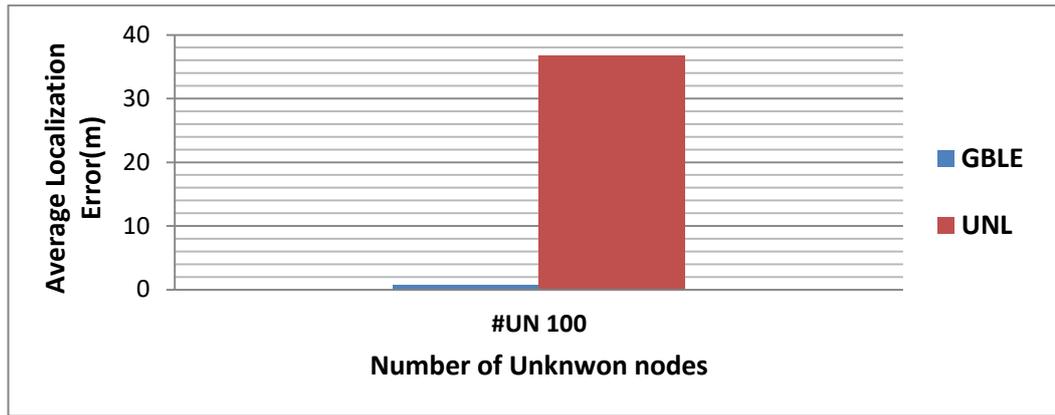
**Figure 4.3: The Average Localization Error with 70,100 Sensor Node and CR 20 m**

Figure 4.5 illustrates the performance evaluation of the GBLE algorithm



**Figure 4.4: The Average Localization Error with 70,100 Sensor Node and CR 35 m**

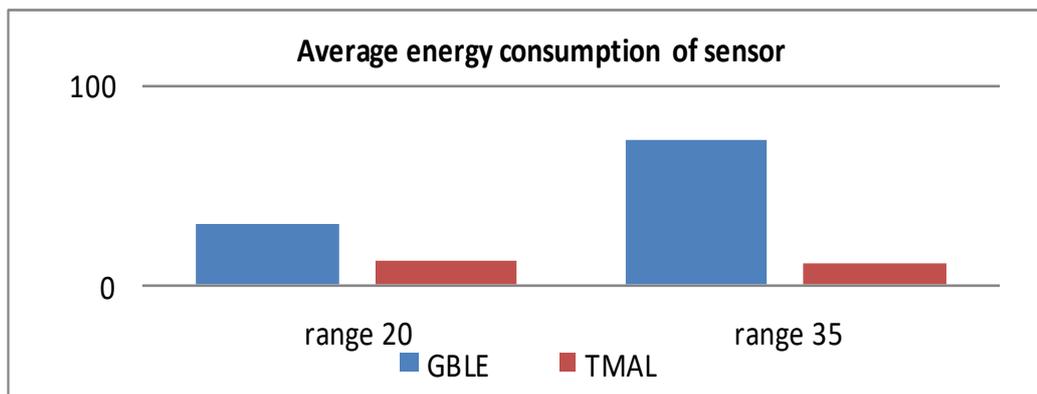
using the second experiment. It depicts the effect of the number of UNs on the average localization error obtained, and the result shows that the GBLE algorithm has a better average localization error when more sensors are deployed in the region while the UNL method showed an increase in the average localization error when increasing the number of sensors in the field. In the GBLE algorithm, the accuracy of the location estimation increases when there are more sensors in the area.



**Figure 4.5: The Average Localization Error with 100 Sensor Node**

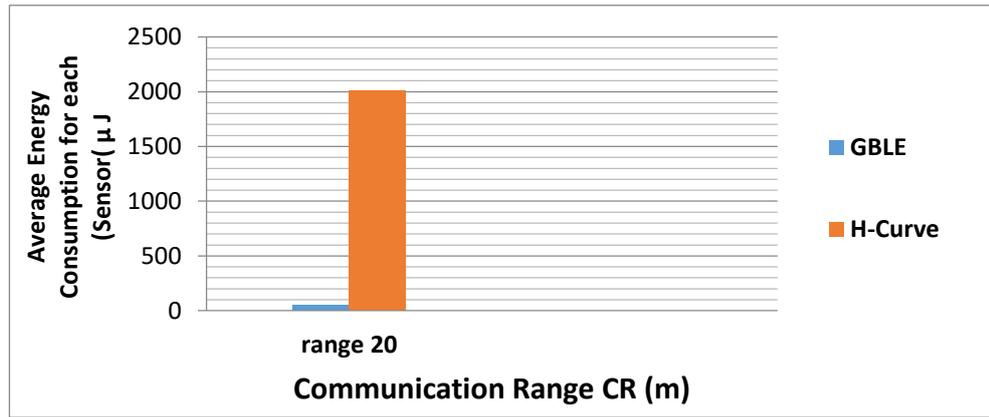
## B. Energy Consumption

To compare the results of the proposed method in terms of energy consumption. Figure 4.6 compares the energy consumption of our method versus the TMAL algorithm with various communication ranges. It demonstrates that the TMAL method in [13] employs mobile anchors, which reduce the number of messages used, whereas our algorithm uses static anchor nodes, which require energy usage to deliver more messages.



**Figure 4.6: Average Energy Consumption of per Sensor for Two Methods in Range 20 and 35 m**

The results of Figure 4.7 showed that our algorithm is better compared to an Algorithm with energy consumption per sensor node.



**Figure 4.7: Average Energy Consumption of per Sensor for Two Methods in Range 20 m**

Table 4.5 is a comparison of various alternative algorithms.

**Table 4.5: Compared with other Algorithms**

<i>Algorithms</i>	<i>Year</i>	<i>UNs</i>	<i>ANs</i>	<i>CR (m)</i>	<i>Average Localization Error (m)</i>	<i>Average Energy Consumption (μ J)</i>
Triple Mobile Anchors Approach for Localization TMAL [13]	2020	70	3	20-35	2.29 – 3.74	-----
		100	3	20 - 35	2.27 - 3.68	-----
unknown node localization UNL [9]	2021	100	4	-----	36.7	-----
H-Curve [12]	2018	250	1	20	-----	2014.5
Graph based Localization Estimation GBLE	2023	70	3	20	0.81	-----
		100	3	35	0.75	-----
		120	3	20	-----	50.7

## 4.6 Summary

In this chapter, we present an evaluation of the performance of the GBLE algorithm when using three anchor nodes to localize unknown nodes in WSNs. The algorithm was evaluated based on a number of different inputs from sensors and CR. Simulation results show that our algorithms have good results compared to other methods. The following points summarize these results:

1. In comparison to other methods, the findings showed that the GBLE algorithm estimated the location of the sensor nodes with good accuracy.
2. Using only three nodes as anchors will help locate any nodes that are not unknown.
3. Using a longer CR and increasing the quantity of sensor nodes within the target region leads to a decrease in localization error. As it causes more connections between nodes, which increases accuracy.
4. The density of UNs effects the accuracy of the model.

## *Chapter Five*

### *Conclusions and Future Works*

#### **5.1 Introduction**

Researchers have given WSNs great attention. This thesis introduces the GBLE algorithm, which relies on static anchor nodes to estimate unknown node locations in the network. In the GBLE algorithm. It uses message path strings and distances between neighbors to estimate the positions of nodes. Our study assessed the proposed system in precision and energy consumption, comparing it to alternative methods. In this chapter, conclusions and suggestions for future works are illustrated after applying the proposed system.

#### **5.2 Conclusions**

After applying the suggested system, some conclusions can be listed as follows :

1. Using only three anchor nodes to estimate node in the network, we obtained high localization accuracy compared to other methods.
2. Using a longer CR reduces the localization error with the UNs until the positions of the UNs are localized. Energy consumption is increased as a result.
3. The study discovers that the anchor is placed in the middle of the area field to estimate the nodes' locations in wireless sensor networks. This approach enhances accuracy and reduces energy consumption during detection and routing.

4. Depending on the GBLE algorithm, the study finds the density of the sensors in the field increases the localization accuracy.
5. Neighbors detection and routing of neighbor's information are distributed, while the estimation of locations is centralized.

### 5.3 Future Works

The suggestions for future works can be shown as follows:

1. In the context of the GBLE algorithm environment, nodes with a degree of less than three within the field domain were not considered. This decision was based on the assumption that a minimum of three sensor node contacts are present in the sensor domain. As future work, a study of the effect of localization accuracy and localization rate on this case can be done.
2. To speed up routing, mobile anchor nodes are used. Routing protocols can benefit from this estimated location data because sensor nodes can now estimate their positions more precisely thanks to mobile anchor nodes. This may result in better routing choices, less energy use, and improved data forwarding.
3. Graph layout can be used to approximate the locations of unknown nodes. In wireless sensor networks, the graph's shape plays a significant role in determining where nodes are located. This process is crucial for optimizing the usage of the collected data and guaranteeing efficient network performance. Graph layout makes use of mathematical, statistical, and artificial intelligence tools to effectively arrange and distribute nodes according to various criteria and purposes.

## المخلص

في العديد من تطبيقات شبكة الاستشعار اللاسلكية (WSN) يعد الحصول على معلومات دقيقة عن موقع العقد أمرًا ضروريًا. تشمل هذه التطبيقات نطاقًا واسعًا، بما في ذلك التوجيه المعتمد على الموقع، وأنظمة التتبع، والشبكات الديناميكية، وأنظمة مراقبة الصحة. يدور التركيز الأساسي لمعظم الأدبيات في هذا المجال حول الأهداف المزدوجة المتمثلة في تقليل الخطأ والحفاظ على الطاقة. تسعى هذه الأطروحة إلى تقديم نهج مبتكر لتوطين إحداثيات العقد داخل شبكات WSN.

يستفيد هذا النهج من استخدام الرسوم البيانية وقياسات مؤشر قوة الإشارة المستلمة (RSSI) لتقدير المسافات بين كل عقدة استشعار والعقد المجاورة لها في المجال المستهدف. بعد ذلك، تقوم عقدة الحوض المركزية (Sink) بجمع هذه المعلومات لإنشاء الرسم البياني للشبكة وتقدير مواقع العقد الدقيقة. تم تنفيذ الخوارزمية المقترحة بدقة باستخدام منصة محاكاة Net Logo و C#. يرتكز تقييم أداء هذه المنهجية على المقاييس المزدوجة للدقة واستهلاك الطاقة لعقد الاستشعار.

وتؤكد النتائج التجريبية فعالية هذا النهج، لأنه يعزز بشكل ملموس دقة الموقع مع تخفيف أخطاء الموقع. بالمقارنة مع الأدبيات الموجودة، تظهر الطريقة المقترحة نتائج جديرة بالثناء من حيث الدقة، مع متوسط خطأ يقع ضمن النطاق الضيق من ٠.٧٣ إلى ١.٢٣ متر.



وزارة التعليم العالي و البحث العلمي

جامعة بابل

كلية العلوم للبنات

قسم علوم الحاسوب

**تحديد المواقع في شبكات المستشعرات اللاسلكية بالاعتماد على  
نظرية المخططات و قوة الاشارة المستلمة**

رسالة مقدمة الى مجلس كلية العلوم للبنات في جامعة بابل وهي جزء من  
متطلبات الحصول على درجة الماجستير في علوم الحاسبات

**مقدمة من قبل**

**زينب اياد حميدي**

**بإشراف**

الاستاذ المساعد الدكتور  
**مهدي عبد السلمان**

الاستاذ المساعد الدكتور  
**محمد عبيد مهدي**

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