Modified DV-Hop Algorithm for Localization in Wireless Sensor Network (WSN)

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LETTER OF APPROVAL

The thesis paper titled as “Modified DV-Hop Algorithm for Localization in Wireless Sensor Network (WSN)” is submitted by Maliha Binte Abdullah (ID:2018-1-55-002) and Saifullah Mahmud (ID:2018-1-55-018) to the Department of Electronics and Communication Engineering, East West University, Dhaka which is accepted as satisfactory for partial fulfillment of the requirements for the degree of Bachelor of Science (B.Sc.) in Electronics and Telecommunication Engineering.

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STATEMENT OF AUTHORS

We, Maliha Binte Abdullah (ID:2018-1-55-002) and Saifullah Mahmud (ID:2018-1-55-018) proclaiming that the work has done purely as part of our bachelor's degree in Electronics and Telecommunication Engineering at this university. If any part of this work has been submitted for a degree or other degree at this university or other institution, this will be clearly indicated. We declare that our work has never been submitted and approved for degree by this or any other university. To the best of our knowledge and belief, this thesis does not contain any material previously published or written by others, unless appropriate references are made in the thesis itself. We hereby declare that the work presented in this thesis is the result of an investigation we have carried out under the supervision of Dr. Anup Kumar Paul, Associate Professor, Department of Electronics and Communication Engineering, East West University, Dhaka, Bangladesh.

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ABSTRACT

Localization is an important aspect of wireless sensor networks (WSNs). A wireless sensor network consists of a large number of small, low-cost, low-power sensors with limited processing power that communicate with each other on an ad-hoc basis. The physical coordinates of the sensor nodes within the decision task WSN are called localization or positioning. A key component in today's communication systems for estimating the origin of an event. B. Different location accuracy requirements for different applications, different localizations. Focusing on the latter, this post explores different measurement techniques and strategies for distance-based and non-distance-based localization. In addition, we discuss various location-based applications in which position estimation is performed. Wireless sensor networks (WSNs) help us monitor our physical environment more closely. Localization is a major challenge in such networks, as the reported data is useless without locating the sensors reporting it. Anchor-based and anchor-free approaches, where the DV hop algorithm is an anchor-based approach. This document modifies the DV hop algorithm. A drawback of the DV hopping algorithm is that it does not work well with sparse topologies. The results show that the accuracy of the modified DV-hop algorithm is better than that of the DV-hop algorithm, and the modified DV-hop algorithm works even in sparse networks.

Contents

Chapter 1

Introduction

1.1 Introduction

Real-time localization and position-based Sensor Networks (WSNs) can be applied in many applications, such as natural resources investigation. In these applications, the information is collected and transferred by the sensor nodes. Various applications request these sensor nodes location information. Thus, locations of sensor nodes are important for these studies relying on the condition that only a small proportion of sensor nodes, called anchor nodes, Other sensor nodes estimate their distances to anchor nodes and calculate positions with multi-lateration techniques. These methods provide satisfactory level of accuracy with a small proportion of anchor nodes. Real-time localization and location-based Accurate, cost-effective, energy-efficient and reliable services are required [1, 2]. Wireless these days Sensor networks (WSNs) can be used in many applications. B. When surveying natural resources: Track targets, monitor inaccessible locations, and more. In these applications the information Collected and sent by sensor nodes. Various applications require these sensor nodes. Location information is also essential for geographic routing. Protocols and clustering [3, 4]. All of the above results in one localization algorithm of the most important topics in WSN research. Therefore, sensor node placement is important. Operations WSN localization has been extensively studied in recent years. These studies show that only a small fraction of sensor nodes, called anchor nodes. One can get the exact location by GPS device or manual setting [5, 6, 7]. Other sensor nodes Estimate distances to anchor nodes and compute positions using multilateration techniques. These methods provide a satisfactory level of accuracy even with a small percentage of anchor nodes. Sensor nodes are randomly deployed on terrain inaccessible by vehicular robots or airplanes and used in many promising applications such as: B. Health Surveillance, Battlefield Surveillance, Environmental Surveillance, Coverage, Routing, Location Services, Target Tracking and Rescue [10], Global Positioning Systems (GPS) or standalone cellular systems are the most promising and accurate positioning technology. Widely accessible, but highly restricted Due to the cost and power consumption of GPS systems, it is impractical to install on every sensor node. Sensor node lifetime is very important. On the other hand, cellular signals are interrupted Scenarios with deep shadowing effects [11]. To reduce energy consumption and costs, only few nodes, called anchor or beacon nodes, contain GPS modules. Other nodes can obtain location information through localization methods. wireless sensor The network consists of a large num-

ber of inexpensive nodes densely distributed over a region of interest for measuring a particular phenomenon. Main goal is location determination sensor node. Node self-localization can be divided into two categories: Range-based localization Area-free localization. The former method uses the measured distances/angles to make an estimate position. Moreover, the latter method uses connectivity or pattern matching methods for estimation site. Various localization algorithms and methodologies have been proposed to address different problems various application issues. A combination of various range-based techniques called Hybrid positioning has sufficient accuracy and cover [14]. Location algorithms, on the other hand, are based on hop distance and hop count. It is well known in the literature to be based on information between anchor nodes and sensor nodes. It outperforms connectivity-based or range-free algorithms. Depending on the method used for estimation, Distance between intermediate nodes, area-free algorithms can be divided into two categories: heuristic, and analytically. Range-free localization algorithms are also classified based on their deployment scenario. The classification is divided into four groups according to his:
(1) Static sensor nodes and static Anchor knots (2) static sensor nodes and mobile anchor nodes (3) Mobile sensor node and static anchor nodes. (4) mobile sensor nodes and mobile anchor nodes There are many localization techniques used to solve positioning problems, WSN has practical limits on the combinations and minimums of these techniques. The number of anchor nodes that can be used in such scenarios. in many situations.
Only one or two anchor nodes can communicate with the sensor nodes to be discovered. Therefore, new positioning techniques are based on hybrid data fusion and/or heterogeneous access proposed and analyzed. This white paper provides a detailed overview of recent localization techniques and concepts their basic limitations, challenges and applications. Literature review on localization Techniques are in and few studies have focused on distance-free localization technology without focusing on newer and more advanced techniques and applications. that's the survey is obsolete, while focuses exclusively on ultrasonic positioning systems works. It covers relatively new localization techniques, but focuses only on indoor localization techniques It also briefly discusses area-free localization. A variety of techniques are discussed in papers
B. A wireless local area network (WLAN) used for indoor positioning. but they don't Neither from the point of view of energy efficiency nor from the recent demands discuss positioning Applications such as environmental assistance and wellness applications. In the summary of, Notable Classification of Various Fingerprint-Based Outdoor Positioning Techniques, Methodology Discussion Any method will work. As such, we plan to present a study that focuses specifically on range-free technologies. Moreover, with the rapid growth of various localization approaches in this field [8].

1.2 Inspirition

In recent years, many scholars have become interested in localization in wireless networks, sensor network, leading to the proposal of some localization algorithms in the document. Both range-based and non-scoped location methods are broadly classifiable these algorithms. Investigating the effects of motion on DV-Hop, based position is one of the goals of several studies. Portability has proven to be significant affects the performance of the DV-Hop algorithm. Accordingly, the position the method currently includes a cellular model.

1.3 Related Problems

The problem with DV-Hop is that the distance calculated by counting the number of hops between the unknown node and the anchor does not match the actual distance. distance between them; as a result, the number of boundaries does not accurately reflect the actual distance. exact distance between unknown nodes U The position and anchor node R1 are not equal to the calculated distance. Two hops between the unknown node U and the anchor node Therefore, to reduce DV hop error and improve accuracy, we need to reduce the uncertainty in the computed distance. Change DV hop. Its first change is based on network subdivision. Divide the area into equal subareas, the second uses two methods to reduce the error and improve accuracy. The second method is also Network range to equal subranges. Use hop count number if other node exists Non-adjacent anchor nodes or RSSI, if any. An unknown location determines its position from its subarea anchor. In two ways, the hop size is determined by the anchor hop count. Not his RSSI packets for the entire network or the anchor, but the same subset. Therefore, it gives an accurate indication of the actual distance between nodes. In this research paper we concerned about finding out the minimum error rate on purpose and hop distance as well Calculating the average hop distance then increasing the accuracy of DV-Hop to compare the traditional DV-Hop results.

1.4 Procedure

This part of the thesis deals with the methods selected for argumentation or analysis of a certain piece of data or a requested scenario. This thesis is based on simulation. Firstly, we have installed MATLAB operating system. Then we assigned the code in the MATLAB command window and executed it. We had to change some important settings in this code and get our expected solutions. Non-scoped methods are divided into categories: centroid algorithm, amorphous, DV-Hop method, multidimensional scaling method (MDS) and approximation point in triangle (APIT) method. Range free localization algorithms can be easily combined simple DV-Hop approach. Therefore, the DV-Hop algorithm is the Most used. Reduce localization errors thanks to DV-Hop method. This algorithm has a localization function. This function requires an anchor node, which provides information about the node's position. Sensor button do position of anchor node and calculate position. This technology provides better scalability and distribution. Accuracy is affected if the distribution of sensor nodes is unequal. As a result, the method provides low positional accuracy. Thereby, DV-Hop algorithm has been improved. The main contribution of the paper is as follows:

- Modified DV-Hop method combines DV-Hop technique with RSSI Measures are presented to improve the accuracy of locating buttons.
- An error analysis was performed to obtain accuracy.

- Improved algorithm to reduce calculation errors.
- The average hop distance formula has been improved.
- Formulas for optimizing the number of hops, unknown nodes, and particles has been updated.
- Modified DV-hop algorithm produces higher quality results and lower error rates.

Chapter 2

Paper Review

The topic of localization in wireless sensor networks has received much attention over the years. Our investigation led us to the conclusion that many locations techniques have been suggested in various publications. However, the position accuracy of the DV-Hop algorithm has a major flaw and needs to be improved. However, many alternatives and more efficient algorithms for DV-Hop have been developed. Although location based on distance can provide exact location. In [9], the algorithms required to do this are complex, expensive, and energy-intensive. Therefore, several gapless localization techniques have been presented. By finding the shortest paths between the anchor nodes of the pair, the DV-Hop method starts with calculate the jump distance between them. Buttons that act as anchors have locations have been determined. These nodes can calculate the average jump distance along these lines by dividing the Cartesian distance between them by the corresponding number of balls. Since the sensor nodes already know the distance, they as anchor, they can use this information in conjunction with the mean hop length to estimate their distance from each anchor in the network. Article [3] presents two improved algorithms: Checkout DV-hop and Selective 3-Anchor DV-hop. In the first case, the mobile node's position is estimated using the DV-hop Checkout technique, using the anchor point closest to the node. To mitigate this, we use an algorithm called Selective 3-Anchor DV-hop to select optimal anchor trio for the job, reducing position errors. Because in summary, this work provides a comprehensive demonstration of the effectiveness of the standard The algorithms are based on DV-hop by emulating the DV-hop protocol. To better locate sensors in wireless sensor networks, the authors of [11] presented a genetic method. The first contribution of this study is a mathematical optimization model using the distance between unknown nodes and anchor nodes. Then a genetic algorithm is used to solve the optimization model. Includes vex-to-hop distance and approximation point in a triangle (APIT) create combined position technique (DV-HOP) including vex-to-hop distance and approximation point in triangle (APIT) to create combined localization technical (DV-HOP). Using Vector Hop Distance (DV-Hop) and Approximate Score in triangulation (APIT), a combined position approach proposed in [11], can be used to determine the accuracy of a given position. First, we use corner detection to determine the exact title of the mystery buttons. Then the APIT. algorithm is applied to each unknown node of the triangle. The latter uses DV-Hop the algorithm assigns different weights to each node on the shortest possible path between them. The authors of[3] also claim to have improved localization accuracy with the DV-Hop placement method uses the RSSI backend scope and an error correction technique based on the neighborhood centroid of the target sensor node. DV-Hop technique, a fundamental component of this localization process, which was originally used to provide an estimate of the location of each sensor node. A positioning error model is then calculated for each sensor node by taking the difference between its center of gravity and its predicted position from the centroids of its neighbors. With this positioning error in hand, RSSI closes the gap between the selected point node and its neighbors in the maximum probability calculation. In [13], the author introduced a new variant of DV-Hop (NDV-Hop). WSN positioning method. Their proposed technique reduces the need for network-wide communications, allowing for faster positioning and lower power consumption. The Location accuracy is another goal. The position of an unknown node is calculated using unlimited optimization to reduce the estimated distance error to minimum. Advanced DV-Hop algorithm (IDV-Hop) [7] is enhanced by worked in [13], which increases the communication cost of the method. Another improved DV jumping technique with lower node position error is proposed in. Since estimating the variance of the distance estimation error requires a lot of computation, although this method increases the accuracy of the position in original DV-Hop technique, it also requires more computer processing time. Both DV-Hop hyperbolic positioning technique and improved center of gravity The DV-Hop positioning algorithm proposed by for wireless sensor networks randomly distributed (IWC-DV-Hop). Because of the original's authors DV-Hop believes that using the average jump size of the anchors is closest to the unknown node is the cause of large error and poor position accuracy, hop size of the anchor node has been replaced by an average of the jump sizes of all anchors in these improved algorithms. Both strategies improve location accuracy of the classical DV-Hop method. DV-Hop is further refined in [10]. The importance of changing the hop size is emphasized. An anchor node calculates the adjusted jump distance and sends it to net. Jump size is simply adjusted with a weighted average of the jumps distance between each anchor node. An alternative to the most popular Triangulation procedure, 2-D hyperbolic localization is used to determine final position. From what we can see in our simulations, the new method can improve accuracy, albeit at the expense of some coverage. To help them find solutions to a set of circle-circle intersection (CCI) problems, Ruizet al. [10] using distance estimation as the lanyard. After analyzing the CCIs, average is calculated to establish the initial node's position and the trending CCIs selected group. The results show that the proposed method is robust against existing localization algorithms that have been refined for performance gain. A localization approach based on Shuffled Frog Leaping and Particle Swarm Suggested Optimization (PSO) [3]. After determining the average distance between per hop using SFLA, unknown node position is considered optimization problem and solve with PSO. In terms of location accuracy, it is superior to DV-Hop algorithm. Location in wireless sensor networks is a hot topic these days. Our investigation leads us to the conclusion that many localization techniques have been offered in various publications. However, the location accuracy of DV-Hop. The algorithm has a big flaw and needs to be improved. Many alternatives and more efficient algorithms for DV-Hop however have been developed. Although distance-based positioning can provide precise location in [9], the required to do so is complex, expensive, and energy-intensive. Therefore, several gapless localization techniques have been presented. By finding the shortest path between the anchor nodes of the pair, the DV-Hop method will first calculate the jump distance between them. Nodes that act as anchors have their positions determined. These nodes can calculate the average jump distance along these lines by dividing The Cartesian distance between them is equal to the corresponding number of marbles. The words sensor nodes already know how far they are from the anchor, they can use This information is combined with the average hop length to estimate their distance from each anchor point in the network. Article [3] presents two improved algorithms: Checkout DV-hop and Selective 3-Anchor DV-hop. In the first case, the mobile node's position is estimated using the DV-hop Checkout technique, using the anchor point closest to the node. To mitigate this, we use an algorithm called Selective 3-Anchor DV-hop to select optimal anchor trio for the job, reducing position errors. 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Then the APIT. algorithm is applied to each unknown node of the triangle. The latter uses DV-Hop the algorithm assigns different weights to each node on the shortest possible path between them. Like DV-Hop, the amorphous technique is based on offline jumping distance calculation and the assumption of a certain network density. He suggested creating an exact coordinate system on distributed processors using only local data. Based on according to Kleinrock and Silvester's formula, we can determine the hop distance. Because propagating the beacon, each node will know its distance from the anchor points. an unidentified person node averages the hopping distances of neighboring nodes. By triangulation, the position of a node can be calculated by first determining its estimated distance to three anchor.

Chapter 3

Basic measurement techniques for localization of WSN

Location is widely used in Wireless Sensor Networks (WSNs) to determine the current location of sensor nodes. A WSN consisting of thousands of nodes makes it expensive to install GPS on each sensor node, and moreover, GPS will not provide accurate location results in an indoor environment. Through localization, the approximate location of sensor nodes in the network is determined. To ensure successful data transmission over the network, this process is very important. Anchor nodes, roaming nodes, and central servers make up the location network of the WSN. The detectors communicate with each other using radio waves. Nodes that know their place in the network are called "anchors". It can be powered by batteries or an external source and is equipped with additional GPS. Location methods can be divided into several different categories, including those based on coordinates, proximity, angle, range, and known distance from the user's current location. Range-based location and distance-based location are the same but divided into different categories. A device is required to determine the distance for a distance-based location. However, there is no need to determine the position by distance. You may also hear these buttons called "card buttons" if they have an RF transceiver and 8-bit microprocessor. Rechargeable battery and built-in motion detector. Unless put to sleep, the Sensor Button Motion Detector will detect any movement. Improved positioning accuracy can be achieved using mixed source localization methods using higher order non-standard and cumulative signal reconstruction. Other nodes with a reduced number of antennas can be detected using an asymmetric nested network arrangement [14].

When pulse noise is present, it reduces the accuracy of passive source positioning algorithms. Meta-heuristic localization methods are developed to reduce localization errors. Algorithms, centralized or distributed, are used to locate the node. Through the use of distance measurements, nodes can roughly determine their position relative to any given coordinate system. An understanding of the distances or angles between nodes was sought as part of the relative position determination task. A manually configured set of reference or configuration nodes can replace a relative coordinate system. This method is very effective in minimizing interference from GPS receivers. Only a small number of nodes (called anchors) need to know their exact position for absolute position to work; Other buttons are marked corresponding to the position of the anchors. Most absolute position methods use the coordinates of the global positioning system. A GPS-equipped sensor is required for GPS tracking. A select group of nodes with a GPS receiver can act as a reference beacon node. An absolute coordinate system can only be defined using these reference points. Alternatively, by using a linear transformation and a few reference nodes in the absolute coordinate system, the coordinates can be extracted from the coordinates in the relative coordinate system.

By working together, multiple sensor nodes can provide more accurate location estimates, a process known as cooperative location. It broadcasts the location of sensors throughout the system. To build a network topology, sensors share data and perform computations in a decentralized and peer-to-peer manner. To do this localization, we compare the positions of an unknown number of nodes. draw attention to the fact that this tactic has two advantages. For starters, there is a significant improvement in the ratio between the anchor nodes and the sensor nodes in terms of coverage. Second advantage, location can be located more precisely thanks to more data types between nodes. The following figure shows the Classical and Artificial Intelligence Methods of WSN. In this paper we will work for only the classical method [12].

The WSN positioning algorithm depends on different measurement techniques. Have many factors influence the accuracy of the localization algorithm and therefore the choice of location algorithms for use in various applications. For example, network architecture, sensor density in an area, number of anchor nodes, geometric shape of the measurement area, Synchronization of sensor time and signal bandwidth between sensors are key factors to taken into account when designing a localization algorithm. However, this is the kind of measurement and the corresponding accuracy essentially determines the accuracy of the location algorithm. Measurement techniques in WSN localization can be classified into three categories. Angle of incidence (AOA) measurements, measurements related to radio signal strength and distance profiling technique (RSS). Figure 1 shows the ranking. In the next discussion, we briefly discuss these techniques and their limitations in different WSN applications.

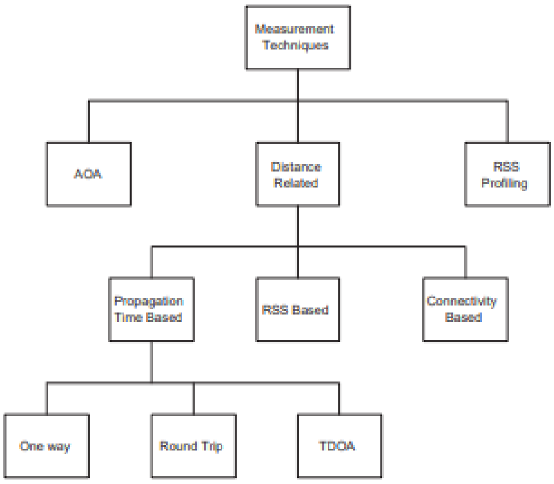

Figure 3.1: Classification of measurement techniques for localization algorithm

3.1 Angle of Arrival (AOA) Measurements

The AOA measurement technique is also known as directional or directional measurement. incoming measurement. AOA measurements can be obtained from two types of techniques:
one of the amplitude response of the receiving antenna and one of the phase response of the receiving antenna Reply. These techniques calculate the angle at which the signal arrives from the anchor node unknown sensor nodes. Then, the unknown sensor area is a straight line with a certain angle to the anchor node. In the AOA measurement technique, at least two anchor nodes are required to calculate the position. Location error can be big if there is a small error maybe. Accuracy depends on antenna's orientation and measurements further complicated by the presence of shading and multipath environment. The multipath component of the transmitted signal may appear as a signal from completely different directions and thus cause very large errors in measurement accuracy. Therefore, the AOA technique has limited value for positioning unless used with large antenna arrays[8]. Therefore, for WSNs with small sensor nodes, this option is not at all power efficient.

3.2 Distance Related Measurement

Distance-related measurements can be classified as propagation time measurements (one-way, round trip and time difference arrival (TDOA)), based on RSS and connection measurement based.

3.2.1 Propagation Time Measurement

In one-way delay measurement, the main approach is to measure the difference between the transmission of the transmitted signal and the reception of the signal at the receiver. The distance between transmitter and receiver is then calculated by this time difference and the propagation speed of the signal in the medium. Measuring time is a relatively mature method domain. However, a major limitation in performing one-way delay measurement is this, it requires synchronization between the local time at the transmitter and the local time at recipient. Any difference between the local time at the transmitter and the receiver will result in the distance estimation error is large and therefore the position estimation error will be large. In speed of light, a very small 1 ns time error will result in a distance measurement error 0.3 m. Precise timing requirements can add to the cost of sensor nodes, by requiring a very precise clock or can add complexity to the sensor network by asking for a complex synchronization algorithm. This limitation makes this option less appealing to WSN location.

//The round-trip delay measurement measures the difference between the time when a signal sent by a sensor node is returned from the second sensor node to the first sensor node. In this technique, no time synchronization is required, since the time difference is measured at the send sensor node uses the same local clock. The main cause of errors in this technique is the delay required for the second sensor node to process the signal, process it, and send it back. This internal delay is known through a priori calibration or measured at the level of the second sensor node and back to the first sensor node where it was subtracted. In addition to the synchronization problem, round-trip and round-trip delay measurements are affected by noise, signal bandwidth, environment without straight line and multi-way line of sight. To overcome some limitations, Ultra Wide Band (UWB) was used to measure the propagation delay precisely. UWB is achievable. The accuracy is very high because its bandwidth is very wide and therefore its pulse duration is very short. This feature allows for fine time resolution of UWB signals and thus separation of multiple paths possible signals.

//The arrival time difference index measures the difference between the arrival time of signal is transmitted to two separate receivers respectively, assuming the positions of the two receivers are known and they are perfectly synchronized. This technique requires three receivers to determine the location of the transmitter. Accuracy is affected by timing error and multipath. Accuracy improves as the distance between receivers increases as this increases difference in the future.

3.2.2 Received Signal Strength (RSS) Based Measurement

The received signal strength measurement estimates the distance between two magnetic sensor nodes received signal strength of the signal. Most sensors are capable of measuring RSS. The estimated distance from RSS is a monotonous descending function. Modeled relationship according to the following log-normal model:

$$P_r(d)[dbm] = P_0 d_0[dbm] - 10n_p log_{10}\frac{d}{d_0} + X_\sigma \tag{1}$$

where $P_0(d_0)[dBm]$ is the reference power in dB milliwatts at the reference distance d0 from the transmitter, np is the path loss exponent measuring the rate at which the received signal strength decreases with distance, X is a zero mean Gaussian random variable with standard deviation and it takes into account for random effects caused by shadows. np and depend on the environment. Show model and model parameters, known by a priori measurements, the distance between two sensor nodes can be obtained from RSS measurements. The localization algorithm can then be applied to use this distance and estimate the position by multimedia techniques. Receiver is the main method. In this approach, distance is measured by estimating the length of time the receiver is in the optical beam. The advantage is optical receiver small size and low cost. However, it requires line of sight between transmitter and receiver.

3.2.3 Connectivity Based

Connection-based measurement is the simplest of all measurement techniques we have discussed so far. In this technique, one sensor is connected to another sensor if it is in the radio each other's transmission range. Such measurement technique is considered binary measurement. In this technique, a sensor node is connected to another sensor node (binary 1) or not directly connected. If it is outside the radio transmission range (binary 0). From sensor to sensor, the distance so expressed by the number of hops and different algorithms are applied to measure the average hop distance as precise as possible. This category of WSN positioning algorithms is popular is called the scope less localization algorithm.

3.3 RSS Profiling Measurement

The RSS-based measurement estimates the distance between sensor nodes, as shown in previous part. The location algorithm then uses this distance to calculate the location sensor buttons. However, implementations of this type of algorithm encounter two challenge:

- First, the wireless environment, especially the indoor wireless environment, and outdoor wireless environment with uneven objects inside the measuring area, make a distance Estimating from RSS is difficult.
- Furthermore, second, the definition of model parameters also a very difficult task.

To overcome these difficulties, the RSS profile measurement technique estimate sensor position from the map RSS measurements are used to improve accuracy RSS profile measurement works by first constructing a form of signal strength map of anchor nodes at different positions in the measuring area. Map taken offline through a priori measurements or online by deploying eavesdropping devices at a number of known locations. This type of technique is mainly used for WLANs, but they look interesting also for WSN. In RSS profile-based navigation systems, in addition to anchor nodes and unknown sensors nodes, a large number of sample points, e.g. eavesdroppers or distributed reference points throughout the coverage area. At each sample point, the intensity of the received RSS signal from different points anchor nodes, where the nth entry is the nth anchor node. Of course, different items have different signal strength, and many of them are zero or close to zero do great distance from anchor nodes. All these points make up the RSS map of region of interest and is a unique signature corresponding to the anchor locations and the wireless network Environment. Models are stored in a central location. An unanchored node estimates its position by refer to the RSS map. It calculates the signal strength of its current location, then matches the position of the corresponding tag with the nearest signal strength.

Chapter 4

Localization algorithm in WSN

Based on the distance measurement between the sensors, the positioning algorithms in the WSN can be broadly classified into two categories:

- Centralized
- Distriuted

In the centralized location Technically, all measured distances between sensors are sent to a central location where The position of each sensor node is calculated. On the other hand, in the distribution positioning technique, individual sensor nodes calculate their own position using measure the distance from other anchor nodes. The main methods for centralized design the algorithms are Multi-Dimensional Scaling (MDS), linear programming and stochastic optimization algorithm. Some well-known distributed localization algorithms are DV-Hop, DV-Distance and some other algorithms based on the above two algorithms. Centralized and distributed location algorithms are further subdivided into range-based and range-based algorithms. In addition, merging information from different navigation systems with the principles of physics can improve the accuracy and durability of the whole system. This leads to development of another type known as hybrid data fusion [8]. Distance-based positioning technique uses measurement techniques such as AOA, TOA, TDOA and RSSI as described in the previous section to estimate the distance between sensor nodes then calculate the position. Distance-based techniques are usually very accurate but requires additional hardware and consumes more power. In the following subsection, we focus on the scope Free localization and hybrid data consolidation techniques.

4.1 Range Free Localization Algorithm

Localization technique without scope, completely dependent on the content of the received message packet and is a much cheaper solution than many range-based positioning techniques in WSN.

4.1.1 Hop Count Based

Almost all out-of-range positioning techniques primarily use hop-based information to position calculation. DV-Hop and Centroid are pioneering approaches of their

kind. Centroid is designed for sensor nodes that have at least three neighboring anchors. Assuming that sensor node N has three neighboring anchors A1, A2, A3, whose coordinates are (x1, y1), (x2, y2), and (x3, y3) and all nodes have equal communication range. Centroid's principle is to consider center point N as centre of anchors as estimated position. N centroid's location, noted because (xcentroid, ycentroid) can be calculated as (xcentroid, ycentroid) = ((x1 + x2 + x3)/3, (y1 + y2 +y3)/3). Centroid has very low communication and computation costs and can become relatively good accuracy when distributing anchors at regular intervals. However, when the anchor distribution is even no, the estimated location obtained from the Centroid algorithm will be incorrect. On the other hand, the DV-Hop and terrain-hop count-based method requires a small number of anchors. DV-Hop plays an important role in many localization methods to provide baseline distance estimates from sensor nodes to anchor nodes. DV-Hop propagation estimates the distance between anchor nodes expressed as the number of hops through the WSN. The anchor nodes can then estimate the mean distance of each jump, which each sensor node calculates its estimated distance to the anchor nodes. By multilateralization, the localization is then calculated as follows:
Let (x, y) be the unknown node D's position and (xi, yi) i.e. known position of ith anchor node receiver.
Let's say the ith anchor node distance to unknown nodes are di and the total number of anchors deployed in the network is n. Then here is the following formula to calculate the position in location has no scope.

$$\begin{cases} \sqrt{(x-x_1)^2+(y-y_1)^2} & = d_1 \\ \sqrt{(x-x_2)^2+(y-y_2)^2} & = d_2 \\ \vdots & \vdots \\ \sqrt{(x-x_i)^2+(y-y_i)^2} & = d_i \end{cases} \tag{2}$$

$$A = -2 \times \begin{pmatrix} x_1 - x_n & y_1 - y_n \\ x_2 - x_n & y_2 - y_n \\ \vdots & \vdots \\ x_{n-1} - x_n & y_{n-1} - y_n \end{pmatrix} \tag{3}$$

$$B = \begin{pmatrix} d_1^2 - d_n^2 - x_1^2 + x_n^2 - y_1^2 + y_n^2 \\ d_2^2 - d_n^2 - x_2^2 + x_n^2 - y_2^2 + y_n^2 \\ \vdots \\ d_{n-1}^2 - d_n^2 - x_{n-1}^2 + x_n^2 - y_{n-1}^2 + y_n^2 \end{pmatrix} \tag{4}$$

$$P = \begin{pmatrix} x \\ y \end{pmatrix} \tag{5}$$

where, $P = (A^T A)^{-1} A^T B$

However, DV-Hop requires not only uniformly deployed WSNs but also the same attenuation of signal strength in all directions. To modify the disadvantage of existing DV-Hop localization algorithm, the relevant literature proposed many improved algorithms based on the following metric:

4.1.1.1 Improvement based on node information and nearest anchors

There are still some Shortcomings of improved algorithms based on average hop distance. B No Significantly improved localization accuracy, especially when transmission paths are not straight But it redirects. These approaches are accurate only if the topology is isotropic. H. Shortest The path between anchor and sensor approaches the Euclidean distance. however, Large errors in distance estimates if the topology is not isotropic or contains holes. Therefore, some modified methods using anchor knots have been proposed Information and relationships between anchor nodes and sensor nodes or topological structures Information about improving DV hop localization methods. To reduce the effect of holes (obstacle geometry), Shang et al. Assuming the shortest anchors, we propose to use only the four closest anchors. The path to the nearest anchor is less susceptible to irregularities, which gives better results. However, it has the drawback that in some cases you can accidentally destroy some good anchors Improved localization accuracy.

4.1.2 Analytical Geometry Based

The most popular alternative to range-free localization algorithms are based on analytics. Algorithms that theoretically estimate the average hop distance. Statistical properties of grid extension. The resulting average hop distance is local computable at each sensor node and other distance less methods that need to be transmitted other sensor nodes. To address the problem of network anisotropy, a pattern-driven localization scheme. For anisotropic environments, two methods have been developed in this paper to compute estimates. The distance between the anchor and the sensor, based on whether the anchor is slightly or significantly deviated from the normal sensor node. For slightly redirected anchors, use the following information: The closest anchor (or reference station) and its reference station must be within 3 or 3 ranges. Jump 4 from the normal sensor node. That is, the anchor distribution density must be very high. I've developed a method to discard anchors that are heavily bypassed. but no Viewing the number of anchors that fall into frequently redirected categories (since this may not be possible) Identify which anchors are easily bypassed and which are moderately or strongly bypassed. The authors deal with this problem in [7, 9] by computing the detour angle. Between anchor nodes and sensor nodes. Another analysis algorithm states that the average jump distance is There are not enough hops between the anchor and sensor nodes to compute an accurate position. sensor node. It also depends on the number of transfer nodes (transfer all data between the 2 nodes).

4.1.3 Mobile Anchor Based

In this technique, a mobile anchor with GPS capability is periodically moved into the detection area send the current geometric coordinates. Other sensor nodes collect position coordinates of the mobile anchor node. The sensor node then selects three non-collinear coordinate points. It uses various mechanisms to estimate position. Periodically send your current location coordinates. Keep adjacent sensor nodes Tracing in and out of anchor points to build code for communication range. The sensor node repeats this process until it receives at least three coordinate points from the sensor node. Move the anchor node within range. A line segment between these three selected A coordinate point creates two chords in its communication area. Perpendicular bisector later The two strings give the position estimate of the sensor node. To further improve localization first, the intersection of the two selected anchor coordinate points Determines the constraint area of the sensor node. This process is repeated with another two intersections Points to further reduce the range of sensor nodes. Finally, the overall average The intersection point indicates the location estimate of the sensor node.

4.2 Hybrid Data Fusion

Hybrid data fusion is based on the principle of merging information from different data. To realize a positioning system using various physical measurement techniques. In iterative multi-lateration, once the position of an unknown node is estimated, the node is used as an anchor node for other unknown sensor node requires multiple iterations Complete the localization process. Another interesting study uses a technique that combines angle-based localization with maps. Filtering and pedestrian dead reckoning (PDR) with absolute position estimates Angular-based localization techniques. Pedestrian Dead Reckoning enables accurate length and mileage shape. Therefore, the estimate is taken from the angle-based localization technique and PDR motion are merged together with a vector map embedded in the particulate filter used as follows fusion filter. Therefore, combining different information from different positioning techniques yields higher results positioning accuracy. Hybrid data fusion is also used for pedestrian tracking. Classic Hybrid methods were based on fingerprinting RSS methods or map-based methods. On the other hand, another method uses the propagation channel as The model shows a direct relationship between the distance between two nodes and RSS. This approach minimizes calibration costs. Further fusion of inertia Measurement and channel-based localization provide higher accuracy compared to fingerprinting base method. Another hybrid data fusion system uses information from WLAN Smartphone built-in cameras for position estimation. This approach uses visual markers Already installed on the ground for position correction. Combine visual information with radio Data for indoor tracking of tagged people by mobile robots. Again, we presented how to integrate range-based sensors with identity sensors (i.e. infrared or ultrasonic badges). sensors with particle filters for tracking people in a networked sensor environment). As a result, the approach can track people and determine their identities due to the advantages of both sensors. Another method is based on the fusion of video captured from anchors. This method uses a digital compass (magnetometer) to calculate the position of the anchor node. Images captured by video cameras and precise location data for geographically localized ones Reference objects (e.g. single tree, utility pole, furnace chimney, etc.) in the operating area. Digital compasses are cheap, so this method is particularly suitable. For video-based or multimedia-based her WSN where the node is already equipped with a digital compass simply become an anchor knot or whenever a GPS receiver is not deemed suitable. Another author developed a hybrid localization system with configured her WSN. Difference between coarse-grained and fine-grained localization systems. Grainy A localization system takes the strength of the radio signal as a measure of distance to get a rough location. Regions as unknown nodes. The fine-grained localization system is responsible for location refinement. Capture images for finding unknown nodes with the camera sensor node. Therefore, various information fusion leads to improvement of position accuracy, it usually adds complexity. For example, data fusion can also occur with different types of data HF sensors to improve localization accuracy as different localization systems can complement each other each other.

4.3 Comparative Performance of Centralized and Distributed Localization Algorithms

Centralized and distributed algorithms can be compared in several ways:
Position estimation accuracy, implementation and computational complexity, and energy efficiency. Comparing Distributed Localization Algorithms and Centralized Algorithms. It is more computationally efficient and easier to implement in large WSNs. in a way A network type that already has a centralized information gathering architecture. B. Health monitoring, precision agriculture monitoring, environmental monitoring, road traffic control network Measurement data from individual sensor nodes should be collected and processed centrally. Such networks limit the processing power of individual sensor nodes in order to conserve power. Location related data can be piggybacked and sent back to other monitoring data central processing node. Therefore, such a centralized processing algorithm is more convenient Situation as a distributed algorithm using existing centralized architectures. Algorithm Centralization Considering Localization Algorithm Estimation Accuracy provides more accurate estimation results than distributed algorithms. One of the main reasons for this is a centralized algorithm has a global view of the network. However, centralized algorithms have problems Away from scalability issues, it is not at all suitable for large sensor networks. Other cons High computational power of centralized algorithms compared to distributed algorithms Complexity, low reliability due to inaccurate information collected (information can be lost) Collected from the multi-hop sensor node at the central node of the WSN On the other hand, considering design complexity, distributed algorithms are more difficult to design than centralized algorithms due to complex local and global behavior action. In other words, distributed algorithms that perform locally optimally may not behave the same. It is optimally global and an open research question. Distance estimation error between sensors Nodes propagate to other nodes, further reducing the estimation accuracy of distributed nodes algorithm. Moreover, distributed algorithms need many iterations to arrive at a stable solution. Localization algorithms can take longer than some applications allow. Energy required for a particular mode of operation in terms of energy consumption (processing, sending and receiving) specific hardware and sending settings Reach should be considered in centralized and decentralized algorithms. Centralized algorithms require each sensor to transmit location-related information Via multi-hop to a central node, the decentralized algorithm requires only local exchanges Information within a single hop (between adjacent nodes). However, in distributed algorithms, many Such information exchange

(iteration) is required between sensor nodes to arrive at a stable solution.

Chapter 5

Localization based application

Mobile device tracking and navigation is a booming market of expected size $4 billion in 2018 [8]. Reliable, user-friendly and accurate location information for navigation. Mobile users could open the door to many promising applications and new business creation chance. It is therefore considered the foundation for realizing the vision of the Internet of Things (IoT).

5.1 Location-based services

Location-based services provide spatial information to end users via wireless networks and/or the Internet. Applications that provide location-based services can do this provides the necessary context and connectivity to dynamically map the user's location to context sensitive information about the current environment. Location services are geographic locations visited by mobile users. Therefore, this service is also very important indoors and outdoors environment. For example, you can provide location-based services for indoor applications Safety instructions, current cinemas, events and nearby concerts. Also, the application of this Enter the included navigation application to direct the user to a point of interest. location services It is also used for advertising, billing and personal navigation to direct visitors to trade fairs to the goal. It can also be used at bus and train stations to guide passengers to their destinations desired platform.

5.2 Ambient Assisted Living (AAL) and Health Applications

Indoor localization is one of the most common. A key component of AAL tools. AAL tools are advanced tools that run man-machine. Interaction. AAL tools aim to improve the health of older adults by empowering them Check their health. Such applications are used for tracking and monitoring seniors. Part of the indoor localization system based on AAL applications is the "smart floor technology". A “passive infrared sensor” that detects the presence of people and notices their movements. Other applications are based on ultra-wideband technology (UWB). e.g. orthopedics Integrating computer-assisted surgery with intelligent surgical instruments such as wireless probes Real-time bone morphing is implemented. UWB positioning system has been proven to achieve real-time 5.24mm-6.37mm dynamic 3D accuracy. This dynamic precision is therefore Accurate to the millimeter. This accuracy meets his 1mm to 2mm 3D accuracy requirements for orthopedics surgical navigation system.

5.3 Robotics

Robotics is one of the major applications of localization. a lot of research and We are developing to realize the application of multi-robot system. Movement Locating robots in large indoor spaces where collaboration between robots is required is an important factor Application of localization. For example, collaboration between robot teams improves missions Used for surveillance, exploration of unknown zones, guidance, connectivity, etc. maintenance [8]. The Ubiquitous Networking Robotics in Urban Settings (URUS) project is excellent Use case of emergency evacuation localization where robot guides people to the evacuation site. Additionally, obstacle avoidance and dynamic and kinematic constraints It has been considered in robotics to realize a complete navigation system.

5.4 Mobile network

Location information can be used to solve many mobile challenges Network. Position estimation accuracy improves with each generation from cellular networks. For example, accuracy increases from hundreds of meters to tens of meters Cell ID location technology in second generation mobile networks. 3rd generation accuracy Improved based on timing via 4th generation sync and reference signals Used for localization purposes. Localization technology can also be used by many companies A device for realizing position estimation accuracy in future 5th generation mobile communication systems centimeter range. Basically, 5th generation cellular networks are expected to have accurate usage. Location information through all layers of the communication protocol stack. that is We anticipate most of the movement patterns of 5G cellular user terminals and know that these terminals will be associated with fixed entities or people [8]. last but not least Some jobs in cyber-physical systems also require at least localization. B. Smart transportation Systems and robotics in 5th generation cellular systems.

Chapter 6

Evaluation criteria for localization

Evaluating the performance of localization algorithms is important for researchers. Validation of new algorithms against prior art or selection of localization algorithms best suited to the requirements of each application scenario. because of different uses Because of the varying needs, it is important for researchers to decide which or which performance criteria. For metrics, localization algorithms should be compared to other suitable algorithms. A variety of applications are required. A broader set of evaluation criteria would be useful to both developers Users of localization algorithms can fully understand the requirements of their application. Examples of evaluation metrics include localization accuracy, cost, coverage, robustness, scalability. These standards reflect limitations such as: B. Computational Complexity and Constraints, Power consumption, unit price, network scalability. Some criteria are binary in nature, some algorithms may or may not have properties. B. Anchor base or anchor of charge; range-based or no range; self-configuring or not. Researchers can use binary criteria such as Limits the comparative evaluation of algorithms against other algorithms. For example, you can filter Comparative evaluation by designing a self-configuring, boundless localization algorithm by immediately limiting the number of comparisons with range-based solutions.

6.1 Accuracy

Accuracy is defined as how closely the positions estimated by the localization algorithm match. A known ground truth location. A good localization algorithm should provide as many matches as possible. However, location accuracy is not the only primary goal of a good localization algorithm. This is largely application dependent. Each application has different requirements. Position accuracy resolution. Granularity depends on required positional accuracy About node distance. When the distance between nodes is around 100 m, the position error 1m is acceptable. However, if the internodal distance is about 0.5m, there is an error of 1m. Highly unacceptable. It is also important to measure the performance of localization algorithms. Good accuracy even without a complete set of input data. Some algorithms, for example, make this assumption. Measure from every node to every other node so that the localization algorithm reaches a stable result evaluation. This assumption is totally unrealistic given the realities of the deployment environment. The evaluation should show how the algorithm's performance is affected by measurement noise. Bias or decorrelation error in input data. You also need to determine the

number of sensor nodes. It can actually be localized. Errors in measured data are important for these algorithms It was designed to work in 2D and is supposed to work in 3D as well. Measurement because it is a 3D environment Noise can lead to mirroring and reflection of estimated coordinates of sensor nodes. The simplest way to calculate accuracy is to determine the residual between estimates Position and actual position of each sensor node in the network, their sum and average result.
This is called the mean absolute error and is defined as: It is also important that

$$E_{mae} = \frac{\sum_{i=1}^{n} \sqrt{(x_i - \tilde{x_i})^2 + (y_i - \tilde{y_i})^2 + (z_i - \tilde{z_i})^2}}{n} \tag{6}$$

$$E_{rms} = max_{i=1...n} \sqrt{(x_i - \tilde{x_i})^2 + (y_i - \tilde{y_i})^2 + (z_i - \tilde{z_i})^2} \tag{7}$$

the accuracy metric does not just reflect positional error.
It's not just about distance, it's also about the geometry of the network. Using only the average nodal position error. In that case, there is a significant difference in the relative geometric accuracy of the estimated networks Relative geometry of the localization algorithm and the actual network. This issue has been identified from it is addressed by defining the following metric, known as the global energy ratio.

$$GER = \frac{1}{n(n-1)/2} \sqrt{\sum_{i=1}^{n} \sum_{j=i+1}^{n} \left(\frac{\hat{d_{ij}} - d_{ij}}{d_{ij}} \right)^2} \tag{8}$$

$$GDE = \frac{1}{R} \sqrt{\frac{\sum_{i=1}^{n} \sum_{j=i+1}^{n} \left(\frac{\hat{d_{ij}} - d_{ij}}{d_{ij}} \right)^2}{n(n-1)/2}} \tag{9}$$

6.2 Cost

Cost is defined as the cost of the algorithm in terms of energy consumption, communication operational costs, pre-deployment setup (i.e. how many anchors are needed), time to locate a sensor node, etc. An algorithm that can mitigate many of the cost constraints could be desirable if maximization of network life is the primary goal. However, cost is an important trade-off against precision and is often driven by actual application requirements. For example, an algorithm can focus on minimizing complex processing and communication costs to save power, fast convergence, etc., but at the expense of overall accuracy. Some common measures are described below:

6.2.1 Anchor to node ratio

Minimizing the number of anchors is desirable compared to the cost of equipment or from an implementation perspective. For example, using too many anchor nodes in the estimated network their location using the global positioning system must be equipped with a GPS device, both energy-intensive and expensive; thus limiting the overall lifetime of the network. Similarly, predefined anchors positions that are difficult to do if the placement of buttons (including anchors) is done by means (e.g. from an airplane). The anchor-to-node ratio is defined as the total number of anchors node divided by the total number of nodes in the network. This report is very important for the design of a localization algorithm. This metric is useful for calculating the trade-off between location accuracy, percentage of nodes that can be localized relative to the cost of implementation. For example, increase number of anchor nodes will lead to high accuracy as well as possible node percentage is located. On the other hand, implementation costs will increase. A good localization algorithm must study the minimum number of anchor nodes required for the desired accuracy of application.

6.2.2 Communication costs

Since radio communication is considered the strongest process consumption compared to the overall power consumption of a wireless sensor node, minimizing Communication costs are paramount to increasing the overall lifespan of the network. This metric is evaluated based on network size i.e. how much is the communication cost increase as network size increases?

6.2.3 Algorithm complexity

Algorithm complexity can be described as standard concepts (big O notation) in terms of computational complexity over time and space. It is the execution time of the location algorithm before estimating the location of all nodes in the network and the amount of memory(storage) is needed for such calculations. For example, as the network grows, the location algorithm with O (n3) complexity will take longer to converge than an algorithm with complexity is O(n2). The same is true for space complexity.

6.2.4 Convergence time

Convergence time is defined as the time taken from the collection location linked data to calculate location estimates for all nodes in the network. This metric is evaluation related to the size of the network. In other words, how long does it take for the localization algorithm to converge as the network grows. This metric is also important for some fixed number applications of nodes in the network. For example, tracking a moving target requires rapid convergence. And even any location specific algorithm that gives very accurate location estimate but very time consuming is useless in this scenario. Similarly, if one or more nodes are mobile in the network, the time required to The updated location may not reflect the current physical state of the network if the algorithm is slow.

6.3 Coverage

Coverage is simply a measure of the percentage of nodes deployed in a network that can is located, regardless of location accuracy. Some location algorithms may not locate all network nodes. It depends on the density of the nodes as well as the location anchor nodes in the network. When evaluating the coverage performance of location algorithms, one has to try different anchoring scenarios/strategies as well as different knot densities. One can judge how the position accuracy varies depending on the number of anchor nodes, the position of The anchor nodes or neighbors on each node are different. There is a saturation point, then there is no other point get accuracy. However, try to minimize the number of anchors nodes or remove them altogether, the localization algorithm may affect its accuracy and simplicity. Anchorless localization algorithms are often centralized and framed as non-linear optimization problem. These approaches may not be feasible for deployment in resource constrained nodes due to computational complexity.

6.4 Density

If node deployment density is low, it may not be possible to determine much nodes for localization algorithm with random topology due to connection problems. The location algorithm focuses on denser networks so it also supports radio traffic, digital packet conflicts and node power consumption, as these factors will also increase when The number of nodes increases in the network.

6.5 Anchor position

The position of the anchor nodes can have a significant impact on the calculation location accuracy. The location algorithm assumes a uniform grid or a predefined position anchor nodes give them high accuracy but do not reflect the actual situation. As such, these assumptions are impractical for any localization algorithms because they do not take into account environmental factors such as obstacles (affect anchoring), terrain, signal transmission conditions etc. The shape of the anchor nodes relative to the un positioned sensor nodes can have a variable effect on the calculation of the position estimate [9].

Chapter 7

Topologies

7.1 Topology

Defining the real node deployment topology in simulation can play an important role when comparing the performance of localization algorithms. Various topologies like Uniform, C-shaped, S-shaped, O-shaped mesh topologies have a significant influence on the placement accuracy. Sensor network topologies can be mainly divided into two categories: uniform and random. In pairs Topology, sensors and anchor nodes are placed on the network area in a precise grid. Others on the other hand, in random topology, sensor and anchor nodes are uniformly and randomly placed on network area. Figure 2 shows the deployment of nodes in a random topology in the 10m × 10m. area with a sensor density of 8. Between these two topologies, the random topology better reflects the real world deployment scripts. Indeed, in practice, sensor nodes are located in places location is restricted (in the forest) or completely impossible (inside the volcano). In such cases, sensor nodes are often scattered around the deployment area from the aircraft. Therefore, uniform implementation is not guaranteed. For these reasons, random topologies are favored by researchers to evaluate localization algorithms in simulation and comparison with other states of art. Topologies can be divided into regular and irregular topologies according to sensor node placement strategies as well as the shape of obstacles in the network area[14].

7.1.1 Regular topology

In a conventional topology, nodes are evenly placed over an area in the form of a grid or random. In such a deployment strategy, the average node density becomes consistent across each part of distribution area. Many well-known multi-hop localization algorithms estimate shortest path distance (number of hops multiplied by average hop distance) between sensor nodes using this is the advantage of deploying strategy and inferring true Euclidean distance for estimation position of sensor nodes. This gives a very accurate location estimate or at least evaluate. However, this usual topology assumption does not reflect real-world conditions due to Many factors limit the deployment of sensor nodes and are therefore completely inefficient [14].

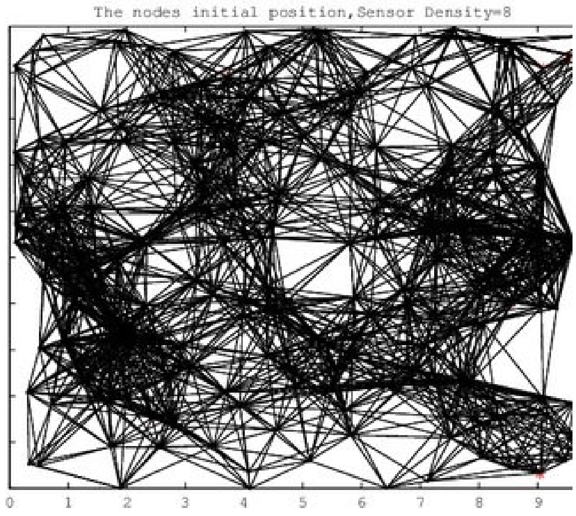

Figure 7.1: Random Regular Topology

7.1.2 Irregular topology

In irregular topology, the estimated distances between nodes are strongly deviated of the actual Euclidean distance due to the presence of obstacles or other objects inside the lattice area. The node density in an individual region can deviate significantly from the average node density of whole region. Depending on the size and shape of the obstacle inside the lattice, the shape of irregular topologies can be C-shaped, S-shaped, L-shaped, O-shaped, etc., as can be seen in the figures show the occasional deployment configurations that many applications can find themselves are constrained by Therefore, such topologies are often useful for comparison and emphasis The various properties of the localization algorithm become powerful. Note that, from the figures the two nodes can be connected via a bypass around the obstacles and thus make a difference between the estimated jump distance and the actual Euclidean distance is large. Therefore, individual Errors in the localization algorithm can accumulate, resulting in large overall localization errors network. Obviously, the localization algorithm that produces correct results in such topologies is considered more powerful and useful in many real-world applications.

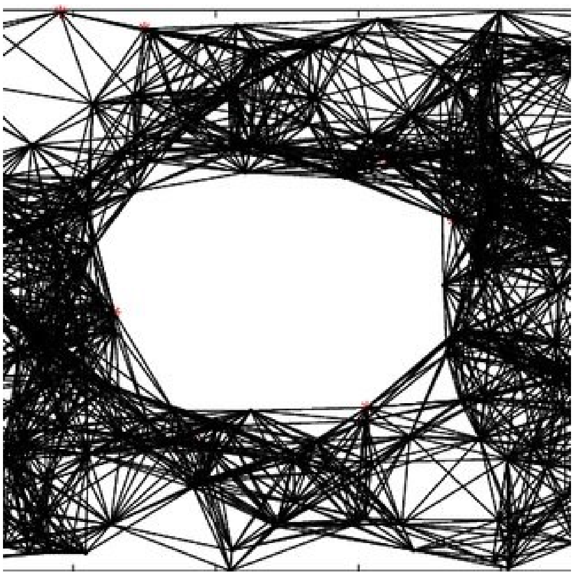

Figure 7.2: O-Shaped Irregular Topology

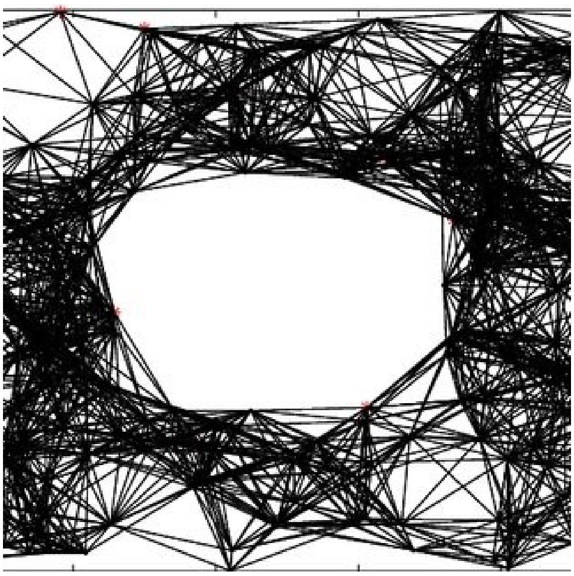

Figure 7.3: C-Shaped Irregular Topology

Chapter 8

Challenges

8.1 Open Challenges for Future Study

In this section, we summarize the different localization perspectives and challenges that need to be addressed be solved. The challenges can be very different in different potential applications.
The network in these applications may be small or large, and the environment may vary. Traditional positioning methods are not suitable for different applications with different environmental conditions[14]. Here are some challenges that need to be addressed:

8.1.1 Combination of different non-radio frequency techniques

Using different non-radio technologies such as image sensors can compensate for errors that exist in current localization algorithms. Improved accuracy can be achieved by installing more expensive equipment. Therefore, researching cost-effective solutions will be a promising research direction in the future.

8.1.2 Integrate different solutions

Various wireless sensors can be used for the purpose position. The physical measurement principles of different sensors are different. Therefore, the integration of Various sensor measurement techniques can improve the overall positioning accuracy of the system.

8.1.3 Ability of extension

An expandable location system means it works well as its range increases bigger. A positional system can often require scaling in two dimensions: geographic scale and sensor density scaling. Geographic scaling means increasing the size of the network area. Other way Increasing sensor density means increasing the number of sensors per unit area. Sensor boost Density poses some placement issues. One of these challenges is information loss due to wireless signal conflicts. Therefore, the installation of the sensor in a dense environment must take into account collision when calculating position information. The third metric in scale is system size. Most of the position algorithms are designed for 2D systems. However, recent recommendations (e.g. FCC recommendation) requires localization in 3D environments. Because in the 3D environment, Measurement noise can cause the estimated sensor node coordinates to flip and reflect. Therefore, a localization algorithm that works well in 2D may not work perfectly in 3D.

8.1.4 Computational complexity

The location algorithms are very complex in terms of software and Material. Computational complexity means software complexity. In other words, how fast is a position The algorithm can calculate the location information of a sensor node. This is a very important factor when the computation is done in a distributed manner. Because, energy is spent on calculation and for a short time battery life sensor, it is highly desirable to have a localization algorithm with less computational complexity. Furthermore, the analytic representation of the computational complexity of different localization algorithms is a really difficult task for the researcher to solve in the future.

8.1.5 Accuracy versus profitability

Different positioning systems have different positioning accuracy and depends on the measurement techniques used to estimate the distance. free range positioning technique, accuracy depends on the number of anchor nodes (pre-installed GPS device) in the network area. Obviously increasing the number of anchors will increase accuracy as well as the cost of the entire system. As such, how to achieve high accuracy with minimal quantity Anchor nodes is an open research problem.

Chapter 9

DV-Hop

9.1 DV-Hop

The DV-hop algorithm is a proven low-complexity localization solution for WSNs. In this configuration, a small group of anchor nodes with known locations act as a source of information for other nodes, which use this data to make informed guesses about their location. In DV, the number of hops is used for estimation, and these numbers can vary from node to node. three anchor nodes send a signal over the network with coordinates and number of hops. Data moves from the node to share information with neighboring nodes. When an adjacent node knows this, the number of hops is increased by one. On the other hand, an un positioned node may go through several hops before reaching the anchor node. The shortest route is calculated by all anchor nodes from all other nodes and by all unlocated nodes from all anchor nodes.

9.1.1 Early stage: (Distance Vector Exchange)

All nodes can get the minimum hop information associated with beacon nodes through the distance vector exchange step. The beacon node floods the network with data packets that include its own information when initiating locating to unknown nodes [10]. The signaling node ID, its location, and the hop value between it and the receiving node are all included in this data.

9.1.2 Second step: (Correction and Dissemination of the Estimated Average Hop Distance)

When an anchor receives hop count information from other anchors, it estimates the average hop size and broadcasts this information to the entire network. The blindfolds multiply the hop size by the hop count value after getting the hop size to determine the physical distance from the anchor. Anchor i calculates the average jump size using the formula below: The smallest hop (hij) between beacon nodes i

$$HopSize_i = \frac{\sum \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum h_{ij}}$$

and j ($i \neq j$), and the coordinates of beacon node i are (xi,yi) and beacon node j are (xj,yj). In order to make sure that the average hop distance is transferred from the closest beacon node to the unknown node, the unknown node will only receive the initial received data, take the average hop distance as its average hop distance, and no longer use and keep all the subsequent adjustments [10]

9.1.3 Third step:

Calculate position of unknown node The number of hops that the unknown node has relative to the nearest signaling node and the defined mean beacon hopping distance correction value node can be used to estimate the distance between the unknown node and each signal button. [8] The appropriate positioning algorithm can then be used to determine the coordinates of the nodes to be determined. A, B and C are signaling nodes are identified by their known position coordinates, as shown in Figure 3.8. Assume AB = 1, BC = 2 and AC = 3 are real values distance between them, where d1, d2 and d3 are known. We can discover the min hop information between unknown node and beacon node as HopSizei estimated mean hop distance from the beacon node above the first and second steps of the DV-Hop algorithm. [10] Average noise of hops will be 2 if the minimum number of hops between A and B is 2, 5 if the minimum number of hops between B and C, and 6 if the minimum number of hops between A and C. Equation (3.6-3.8) shows the card's HopSizeA, HopSizeB and HopSizeC. The nodes A, B, and C are respectively: When calculating

$$HopSize_A = \frac{d_1 + d_3}{2 + 6}$$

$$HopSize_B = \frac{d_1 + d_2}{2 + 5}$$

$$HopSize_C = \frac{d_2 + d_3}{5 + 6}$$

its own average per-hop distance, the unknown node M uses the average per-hop distance of the nearby beacon node B. According to the equation, the hop numbers from unknown node M to the beacon nodes A, B, and C

$$d = HopSize \times h$$

You can calculate the separation between various beacon nodes and unidentified nodes by

$$d_{AM} = 3HopSize_B, d_{BM} = 2HopSize_B andd_{CM} = 3HopSize_B$$

The node's coordinates will then be computed in the last step.
The calculation of unknown node also can be determine using matrix formula. Here we go: Trilateration is used to determine the position of an unknown node. Given that (x, y), (x1, y1),(x2, y2), ...(xn, yn) are the coordinates of anchor nodes, let di be the estimated distance between the unknown node and an anchor i. [4] Deduced are the following set of equations:Trilateration is used to determine the position of an unknown node. Given that (x, y), (x1, y1),(x2, y2), ...(xn, yn) are the coordinates of anchor nodes, let di be the estimated distance between the unknown node and an anchor i. Deduced are the following set of equations:

$$\begin{cases} d_1^2 = (x - x_1)^2 + (y - y_1)^2 \\ d_2^2 = (x - x_2)^2 + (y - y_2)^2 \\ . \\ . \\ . \\ d_n^2 = (x - x_n)^2 + (y - y_n)^2 \end{cases}$$

Then the above Equation can be transformed by:

$$AX = B$$

We define the terms A,X,and B as follows: By solving the Equation and using the

$$X = \begin{pmatrix} x \\ y \end{pmatrix}$$

$$A = 2 \times \begin{pmatrix} x_1 - x_n & y_1 - y_n \\ x_2 - x_n & y_2 - y_n \\ . & \\ . & \\ x_{n-1} - x_n & y_{n-1} - y_n \end{pmatrix}$$

$$\begin{cases} B = x_1^2 + y_1^2 - x_n^2 - y_n^2 + d_n^2 - d_1^2 \\ x_2^2 + y_2^2 - x_n^2 - y_n^2 + d_n^2 - d_2^2 \\ . \\ . \\ . \\ x_{n-1}^2 + y_{n-1}^2 - x_n^2 - y_n^2 + d_n^2 - d_{n-1}^2 \end{cases}$$

least squares method the unknown node can compute its coordinates as:

$$X = (A^T A)^{-1} A^T B$$

9.2 Error Analysis of Original DV-Hop Algorithm

Initial DV-Hop algorithm helps unknown node get Hop Count value of anchor and average jump distance (Hop Size) per flood exchange. Then, using the information received, the unknown node guesses its location. Therefore, the accuracy of the position depends on the accuracy of the calculated value average distance for each jump. However, the calculated average distance for each jump can be wrong and thus leads to a wrong projection position of an unknown node. To illustrate the effect of the average distance per hop on the distance estimate between anchors and unknown nodes, we used the network structure shown in Figure 1. In this example, A1, A2, and A3 represent anchor buttons, and U1, U2, U3, U4 and Un represent unknown nodes. Two buttons connected by an orange line can be directly interacted. The average jump distance (Hop Size) of the A2. anchor can be calculated according to the original DV-Hop algorithm as follows: (70 + 35)/(4 + 4) = 13.125. Then the estimated distance between anchor A2 and unknown node Un, determined by the DV-Hop algorithm, is 13.1251 = 13.125 m. However, in graph, we can observe that the actual distance between the node Un is unknown and the anchor point node A2 is 25 m. Therefore, the calculated distance and the actual distance are not closer. In summary, using the Hop Size of the anchor can create inaccuracies when measuring the distance between unknown nodes and anchors. It is Suggested to make some changes to the original DV-hop algorithm. Most of these methods are based on Hop Size. However, as shown earlier, it is possible to calculate Hop Size contains an error, which will reduce the location accuracy. With this effort, we hope to make the DV-Hop algorithm more efficient in locating unknown nodes. The proposed method focuses on the RSSI of each link between the nodes and uses an approximate polynomial to calculate the distance between anchor and undefined button. Improvements of DV-Hop Algorithm Instead of the average hop distance constraints for each average hop distance [14]. A weighted average hop distance enhanced approach was suggested in the literature. To determine the integrated average hop distance, the unknown node allows M hops within anchor nodes and weights them based on the hop count. A number of neighboring nodes overlap angle computation methods are proposed in the literature to increase positioning accuracy while taking the angle between the three nearby nodes into account. These two were used in the first DV-Hop algorithm to determine the average distance constraints to begin with, but they have raised the unknown node to an anchor node distance complexity. We are interested in stage 2 of the initial DV-Hop and provide a new formulation to calculate the distance between anchor nodes and an unknown node as part of our algorithmic enhancement. In order to improve the accuracy of the estimated distance separating the unknown node and anchor node, we propose in this work to use the average hop distance using the total of the beacon amount divided by the sum of node amount and the sum of unknown node amount. The estimated distance between anchor i and unknown node j can then be calculated using the formula below by inserting the RSSI values: Here, D1 is called the number

$$AvgHopDis = \frac{\sum D1(i,j)}{\sum h1(i,j) + \sum h2(i,j)} + RSSI_D(i,j)$$

of cards; h1 is the number of hops from all signaling nodes; h2 like number of hops from all beacon nodes to unknown nodes; RSSI is the received signal strength index; and d is the distance. To determine the average number of hops, divide the distance between each anchor node and the unknown node with the nearest anchor node by the minimum the number of hops between them. In addition, the initial average jump distance is replaced by the arithmetic mean of the two average hopping distances that have been collected. Equation 3.15 gives a more accurate average jump distance closer to the actual location. The distance between the anchor node and its neighbors is calculated in the process promotional packages. Packets with number, position, hop count and priority information are broadcast by anchor nodes. Command When priority is 0, the initial stage of anchor nodes receives the highest priority. For this test by studying telemetry first without distance, and because inside a hop distance can be significantly smaller than the average distance, the measurement more accurate based on the RSSI range technique. CISO can directly calculate the distance between them and keep it when you want to determine your azimuth unknown knot and single hop anchor knot. Thus, in one jump, the hops of the unknown nodes, the priority information and the new positions of these nodes can used to determine the number of useful anchors for growth.

Chapter 10

Simulation

10.1 Simulation result

The performance of our suggested algorithm is discussed in this section, along with a comparison to the original DVHop algorithm presented in the literatures. We take into account the C-shape and O-shape network topologies for anisotropic networks. Assuming that the anchor node's location is constant, we can assume that all other nodes in the network are also static. The other sensor nodes are not localized, while anchors are because they have a GPS device attached to them. Using MATLAB R2015a, simulation is used to assess the suggested localization process. In a sensing field that is isotropic and 100 meters by 100 meters, we randomly deploy varying numbers of sensor nodes.

Figure 2 illustrates this, with black asterisk symbols designating unknown nodes and red square symbols designating the anchors. Our goal is to locate the unknown node as accurately as possible by estimating its position. We presume that the DV-Hop routing protocol is being used in a multi hop method by each node in the network to connect with one another.

Network Parameter	For Anisotropic Network
Area	100m
Sensor Nodes	200
Anchor Nodes	20
Radio Range	2m

Table 10.1: Network Parameters for Simulation

10.2 C Shape O Shape

10.2.1 C shape

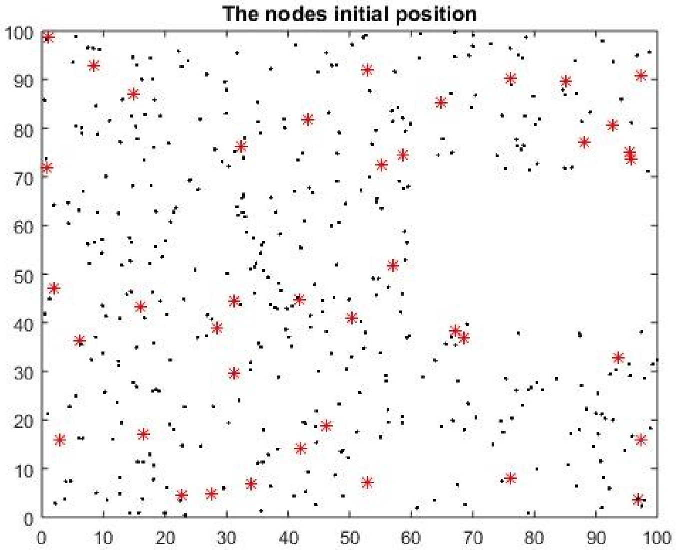

Figure 10.1: The initial position of nodes in C Shape

10.2.2 O shape

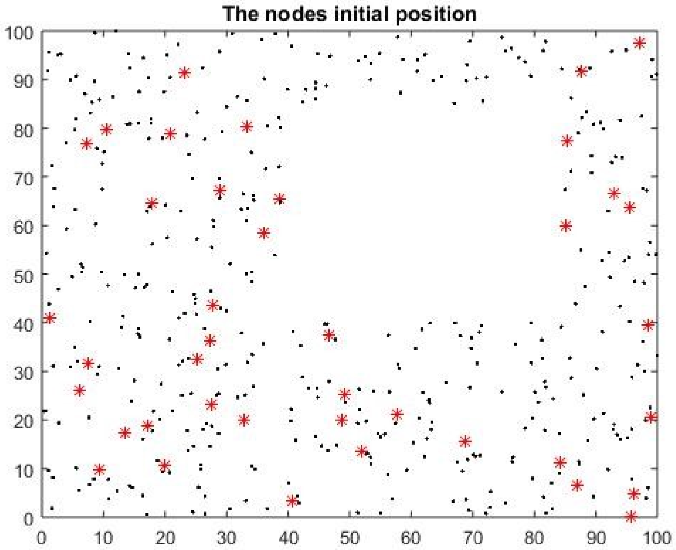

Figure 10.2: The initial position of nodes in O Shape

Discussion:

The DV-Hop localization algorithm's network topology is based on a half-measure adjusted average. Within it the red and the black dots denote beacon nodes and unknown nodes, respectively. Based on the given code after run those the minimal number of hops between nodes is mostly dictated by the communication radius of the nodes. Distance estimation between unknown nodes and beacon nodes is derived by the product of the minimum hop distance and the average hop distance between the two nodes. The larger the node density, the smaller the communication radius, and the topology are closer to the actual place. Varied communication radii will have different hop distances, which will also result in different node locations. Optimizing network topology can also reduce network energy use and increase network lifetime. Here we present both of the C and O shape's result. The shape is more accurate according to the DV-Hop C-shape. The DV-Hop O-shape indicates that the shape is more precise.

10.3 PDF of Average Distance Estimation Error in Anisotropic C Shape and O Shape Networks

10.3.1 C Shape Network

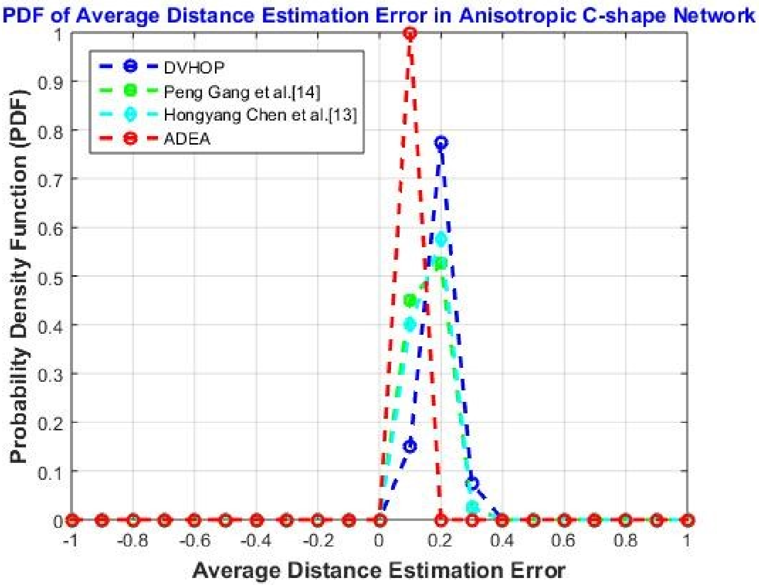

Figure 10.3: PDF of the Average Distance Estimation Error in C Shape

10.3.2 O Shape Network

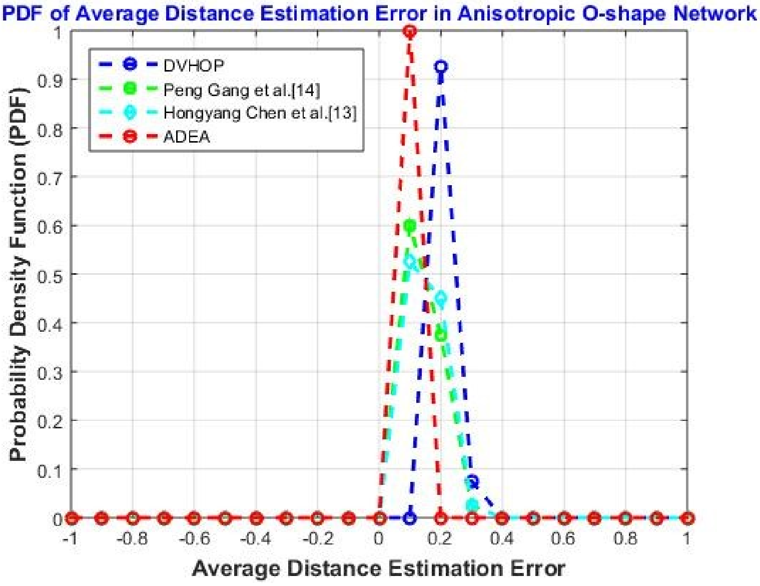

Figure 10.4: PDF of the Average Distance Estimation Error in O Shape

Discussion:

We can observe that our revised approach produces a probability density function with a lower error rate than Peng Gang et al (0–0.4) and Hongyang Chen et al(0.1–0.5) algorithms. On the other hand, the DV-Hop algorithm's error rate ranges from 0.1 to 0.8. On the 1, we measure the maximum PDF errors (ADEA). The DV-Hop measure, on the other hand, has a maximum inaccuracy of 0.2. Consequently, our new method produces superior outcomes. Our updated method generates a probability density function in an anisotropic O-shape network with an error rate between 0 and 0.4. However, the DV-Hop method has an error rate that varies from 0.1 to 0.4. On the 0.2, we measure the maximum possible pdf mistakes. The ADEA, however, bases its maximum error measurement on 0.2. Consequently, our new method produces superior outcomes.

10.4 CDF of Average Distance Estimation Error in Anisotropic C Shape and O Shape Networks

10.4.1 C Shape Network:

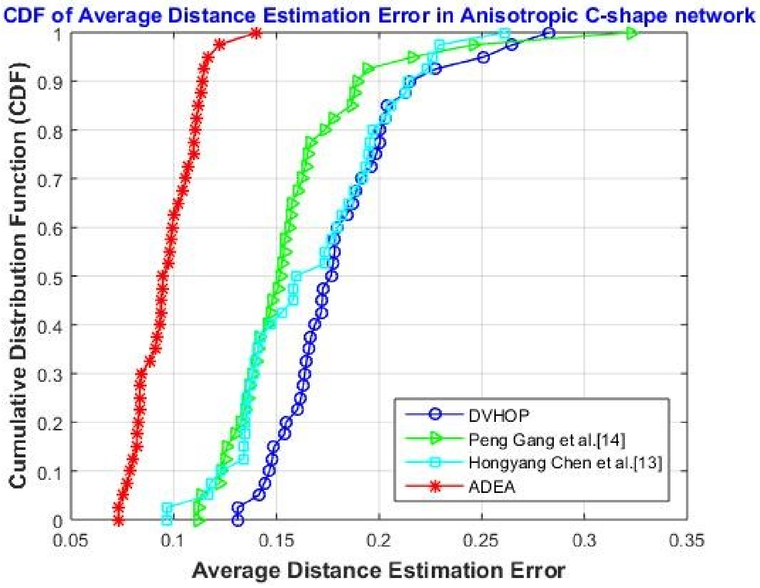

Figure 10.5: CDF of the Average Distance Estimation Error in C Shape

10.4.2 O Shape Network:

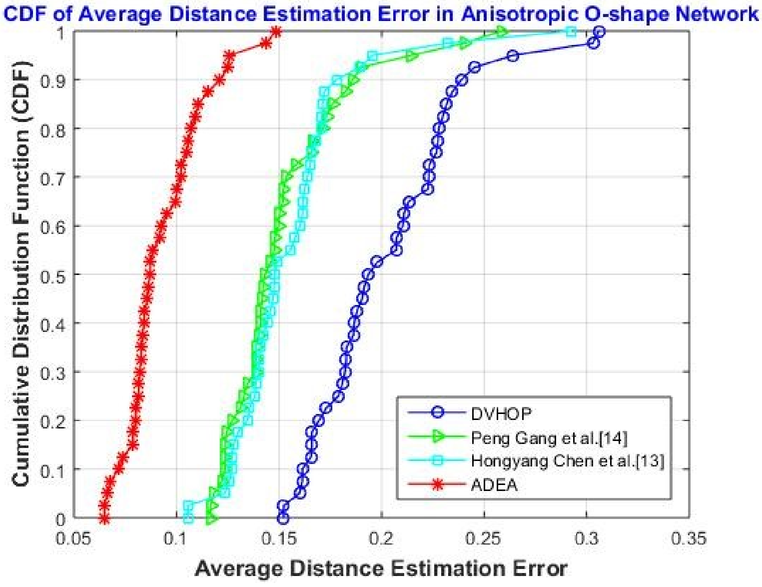

Figure 10.6: CDF of the Average Distance Estimation Error in O Shape

Discussion:

As we can see, our modified strategy results in a cumulative distribution function with an error rate of roughly 0.07. (CDF). The conventional DV-Hop method has an average error rate of 0.13.
On the other hand, we can observe that in the case of the O-shape anisotropic network, our revised approach yields a cumulative Distribution function (CDF) with an error rate of roughly 0.06. The error rate for the traditional DV-Hop approach is 0.15, though.

10.5 The Average Percentage Localization Error Graph

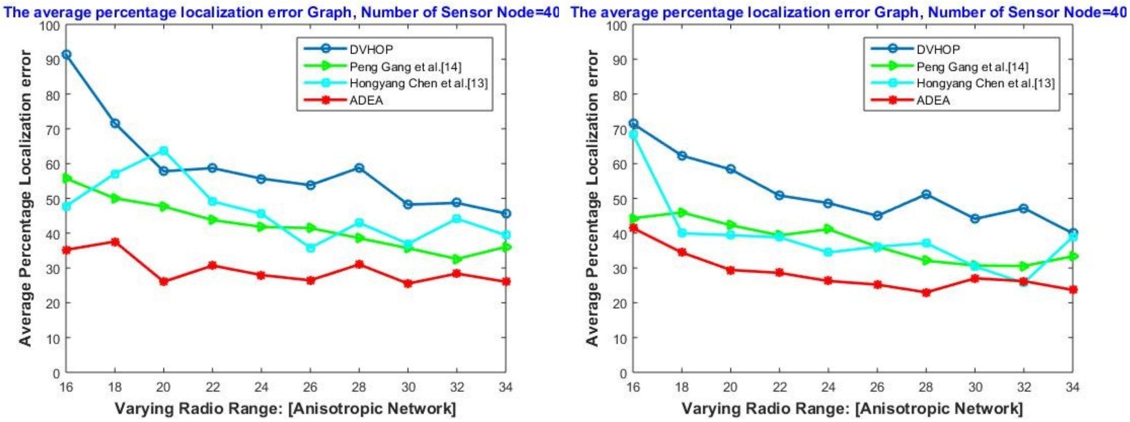

Figure 10.7: The Average Percentage Localization Error Graph

Discussion:

This experiment involves increasing the sensor nodes' radio range from 16 to 34 meters. In the sensing field, 220 nodes with a 30% anchor ratio were planted. According to the c and o shapes, the average localization error of DV-Hop decreases as the communication range increases, whereas the average localization error of the proposed algorithm (ADEA) is steadily declining and the average localization error of the other algorithms is essentially maintained stable. This discovery leads us to the conclusion that, in comparison to DV-Hop, the suggested algorithm is relatively unaffected by changes in the communication radius. Additionally, the suggested algorithm's localization accuracy raises the accuracy of other algorithms. Additionally, the proposed method's average localization error is almost 30% lower than the DV- Hop's. Since the O form had the same situation.

10.6 Average Localization Error Graph

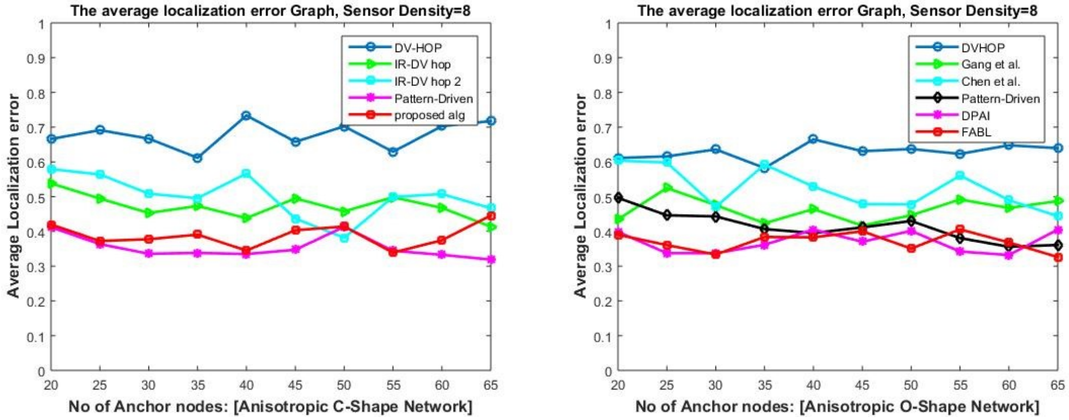

Figure 10.8: The Average Percentage Localization Error in C Shape O Shape

Discussion:

The average localization error for anisotropic networks in C- and o-shapes is shown in the figures. the quantity of anchor nodes and the typical localization error in the x-plane. As opposed to the conventional DV-Hop technique, our revised algorithm appears to have a lower error rate.

The localization accuracy based on the C shape and o shape anchor rose as the proportion of anchor nodes in the network increased, as seen in Figure, which was expected. By increasing the number of anchors, it is possible to maximize the number of inputs to the trinomial equation, which is used by the unknown node to calculate how far it is from neighboring anchors. As a result, a high level of accuracy was reached. The localization error decreases with an increase in the number of anchors in the network for all techniques considered in Figure this is important to note (in these figure). Furthermore, the localization error of the method we devised was lower than that of our rivals.

10.7 Sensor Density in Anisotropic C Shape O Shape Network

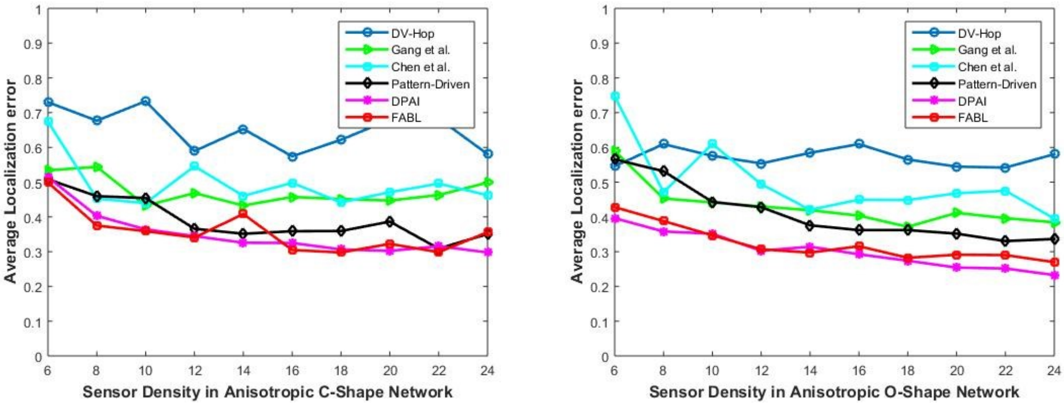

Figure 10.9: Sensor Density in Anisotropic C Shape O Shape Networks

Discussion:

For the C-shape and 0-shape anisotropic networks, it plots the localization error rate versus sensor density. We have the fundamental dv-hop ratio as well as several more sensor density ratios that are the reverse of the average location error here. The lowest mistake in this case is DPAI, and the biggest error is basic dv-hop. From all of these errors, the part that consumes the fewest errors is the best.

Chapter 11

Conclusion

In this study, we use the DV-Hop algorithm to develop a more precise method of locating unknown nodes. Our results show that DV Hop technique can be improved for localization without increase computational cost or require new resources. We simulated at different values and nodes and try to find improvement or that is modification. We have been working on the codes provided to us at beginning and we tried to improve the theories that we worked on. We tried to reduce the error rate of the results which turned out to be one improvement or modification. First, we talk about theory and calculations that are related or help us find a way to correct method. We worked on anisotropic C-shaped and O-shapes. Down here two forms, we worked on anchor node, radio button, unknown button. We find out the result that we have the position of the node, the probability distance function of mean distance function, CDF of probability distance Function, variable radio range, number of anchors and sensor density. All of these images we have shown the real difference with the basic one to modify person. Thanks to this refined technique, the simulation results shows that the placement performance of the algorithm is less affected by the total number of signaling nodes. The disadvantage of this method is we cannot use more GPS sensors due to high cost during installation. When we examine the techniques used in the scale criteria, we can see that if they improve the accuracy, the calculation The effort is quite repetitive. In the future, we hope to study the techniques for positioning and modeling in similar situations, such as localization problems in the signaling and location buttons of the mobile phone wireless sensor nodes.

Bibliography

[1] Kazeem B. Adedeji et al. “Towards Achieving a Reliable Leakage Detection and Localization Algorithm for Application in Water Piping Networks: An Overview”. In: *IEEE Access* 5 (2017), pp. 20272–20285. DOI: `10.1109/ACCESS.2017.2752802`.

[2] Nabil Ali Alrajeh, Maryam Bashir, and Bilal Shams. “Localization Techniques in Wireless Sensor Networks”. In: *International Journal of Distributed Sensor Networks* 9.6 (2013), p. 304628. DOI: `10.1155/2013/304628`. eprint: `https://doi.org/10.1155/2013/304628`. URL: `https://doi.org/10.1155/2013/304628`.

[3] Omar Cheikhrouhou, Ghulam Bhatti, and Roobaea Alroobaea. “A Hybrid DV-Hop Algorithm Using RSSI for Localization in Large-Scale Wireless Sensor Networks”. In: *Sensors* 18 (May 2018), p. 1469. DOI: `10.3390/s18051469`.

[4] Chi-Chang Chen, Chi-Yu Chang, and Yan-Nong Li. “Range-Free Localization Scheme in Wireless Sensor Networks Based on Bilateration”. In: *International Journal of Distributed Sensor Networks* 2013 (Jan. 2013). DOI: `10.1155/2013/620248`.

[5] Yan Chen et al. “An improved DV-hop localization algorithm for wireless sensor networks”. In: *2018 13th IEEE Conference on Industrial Electronics and Applications (ICIEA)*. 2018, pp. 1831–1836. DOI: `10.1109/ICIEA.2018.8398006`.

[6] Jianning Ding et al. “Study on DV-Hop Algorithm Based on Modifying Hop Count for Wireless Sensor Networks”. In: 2012.

[7] Lance Doherty, Kristofer Pister, and Laurent Ghaoui. “Convex position estimation in wireless sensor networks”. In: vol. 3. Feb. 2001, 1655–1663 vol.3. ISBN: 0-7803-7016-3. DOI: `10.1109/INFCOM.2001.916662`.

[8] Stelian Dolha et al. “Considerations about the Signal Level Measurement in Wireless Sensor Networks for Node Position Estimation”. In: *Sensors* 19 (Sept. 2019), p. 4179. DOI: `10.3390/s19194179`.

[9] Benjamin Friedlander. “A passive localization algorithm and its accuracy analysis”. In: *Oceanic Engineering, IEEE Journal of* 12 (Feb. 1987), pp. 234–245. DOI: `10.1109/JOE.1987.1145216`.

[10] Guangjie Han et al. “Localization Algorithms in Large-Scale Underwater Acoustic Sensor Networks: A Quantitative Comparison”. In: *International Journal of Distributed Sensor Networks* 2014 (Mar. 2014), pp. 1–11. DOI: `10.1155/2014/379382`.

[11] Berthold K. P. Horn, Hugh M. Hilden, and Shahriar Negahdaripour. “Closed-form solution of absolute orientation using orthonormal matrices”. In: *Journal of The Optical Society of America A-optics Image Science and Vision* 5 (1988), pp. 1127–1135.

[12] Shihchang Huang and Fu-Gong Li. “A Novel Positioning System Based on Coverage Area Pruning in Wireless Sensor Networks”. In: *Sensors* 18 (Dec. 2018), p. 4469. DOI: `10.3390/s18124469`.

[13] Xiang Ji and Hongyuan Zha. “Sensor positioning in wireless ad-hoc sensor networks using multidimensional scaling”. In: *IEEE INFOCOM 2004*. Vol. 4. 2004, 2652–2661 vol.4. DOI: `10.1109/INFCOM.2004.1354684`.

[14] Anup Kumar Paul and Takuro Sato. “Localization in Wireless Sensor Networks: A Survey on Algorithms, Measurement Techniques, Applications and Challenges”. In: *Journal of Sensor and Actuator Networks* 6.4 (2017). ISSN: 2224-2708. URL: `https://www.mdpi.com/2224-2708/6/4/24`.