

Node Localization in WSN using Trilateration and Multilateration

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Abstract— Wireless Sensor Networks (WSNs) have become an integral component of modern intelligent systems, enabling applications such as environmental monitoring, industrial automation, healthcare management, military surveillance, precision agriculture, and smart city development. In these applications, accurate localization of sensor nodes is critical because the usefulness and credibility of sensed information largely depend on the precise determination of node positions. Consequently, the development of efficient and cost-effective localization techniques has attracted significant research attention. This study presents the design and implementation of a MATLAB-based localization framework utilizing Trilateration and Multilateration algorithms for estimating the coordinates of unknown sensor nodes within a wireless sensor network. The proposed framework employs anchor nodes with predefined coordinates and distance measurements to determine the positions of target nodes. Trilateration estimates node locations using distance information from three anchor nodes, while Multilateration incorporates multiple anchor nodes to improve positioning accuracy and reduce localization uncertainty. The developed model performs coordinate estimation using geometric principles and least-squares optimization techniques. In addition, a graphical visualization module is incorporated to illustrate the localization process and facilitate performance analysis. A comprehensive comparative evaluation is conducted to assess the effectiveness of both localization methods with respect to localization accuracy, computational complexity, error minimization capability, and robustness against measurement noise and distance estimation uncertainties. Simulation results indicate that the Multilateration approach consistently outperforms Trilateration by providing more accurate position estimates and greater resilience to measurement errors. The utilization of multiple anchor nodes enables improved error compensation and enhances overall localization reliability in complex network environments. Furthermore, the proposed framework serves as a practical and economical alternative to Global Positioning System (GPS)-based localization, particularly for indoor, energy-constrained, and large-scale sensor network deployments.

The outcomes of this research establish a flexible platform for the analysis and validation of localization algorithms in WSN environments. Moreover, the work provides a foundation for future investigations involving hybrid localization techniques, optimization-driven positioning strategies, and Artificial Intelligence (AI)-assisted localization methods aimed at achieving higher accuracy and real-time performance in next-generation wireless sensor networks.

I. INTRODUCTION

Wireless Sensor Networks (WSNs). These networks have emerged as a fundamental technology for intelligent monitoring, data acquisition, and real-time decision-making applications. A WSN typically consists of a large number of low-power sensor nodes equipped with sensing, processing, and wireless communication capabilities. Owing to their scalability, flexibility, and cost-effectiveness, WSNs have been widely adopted in diverse application domains, including environmental monitoring, industrial automation, healthcare systems, military surveillance, precision agriculture, smart transportation, disaster management, and Internet of Things (IoT)-enabled smart city infrastructures. A typical sensor node comprises sensing units, microcontrollers, wireless transceivers, and power sources that collaboratively collect and transmit information related to physical or environmental parameters such as temperature, humidity, pressure, vibration, gas concentration, and motion. The collected data are forwarded to a Base Station (BS) or Sink Node for processing, analysis, and decision-making. However, the practical significance of sensed information depends not only on data accuracy but also on the precise knowledge of the geographical location from which the data originate. Consequently, node localization has become one of the most important research challenges in Wireless Sensor Networks. Accurate localization is essential for numerous WSN applications, including target tracking, environmental observation, event detection, network management, and location-aware services. In environmental monitoring systems, localization enables the identification of specific regions affected by abnormal conditions. In military applications, it facilitates threat detection and battlefield surveillance, whereas in industrial environments it supports equipment monitoring, fault diagnosis, and predictive maintenance. Therefore, reliable localization mechanisms play a crucial role in enhancing the effectiveness, reliability, and operational efficiency of wireless sensor networks.

The localization problem becomes increasingly challenging in large-scale deployments where sensor nodes are randomly distributed across remote, hazardous, or inaccessible environments such as forests, disaster-stricken regions, oceans, battlefields, and mountainous terrains.

Manual configuration of node coordinates in such environments is impractical and economically infeasible. Although the Global Positioning System (GPS) can provide highly accurate positioning information, equipping every sensor node with GPS hardware significantly increases deployment cost, energy consumption, and system complexity. Furthermore, GPS performance is often degraded in indoor environments and areas with signal obstructions. These limitations have motivated extensive research into algorithmic localization techniques that can estimate node positions with minimal hardware requirements. Localization methods in WSNs are generally classified into range-based and range-free approaches. Range-based localization techniques utilize physical measurements such as distance or angle information obtained through methods including Received Signal Strength Indicator (RSSI), Time of Arrival (ToA), Time Difference of Arrival (TDoA), and Angle of Arrival (AoA). In contrast, range-free approaches estimate node positions using network connectivity information without relying on direct distance measurements. Among the various range-based localization methods, Trilateration and Multilateration are widely recognized due to their simplicity, computational efficiency, and practical applicability.

Trilateration determines the coordinates of an unknown sensor node using distance measurements from three anchor nodes with known positions. The node location is estimated through the geometric intersection of circles centered at the anchor nodes. Multilateration extends this concept by incorporating additional anchor nodes, thereby improving localization accuracy and reducing the effects of measurement noise, uncertainty, and environmental disturbances. Because of their effectiveness and ease of implementation, these techniques have become fundamental components of modern positioning and navigation systems.

In this work, a MATLAB-based simulation framework is developed to implement and compare Trilateration and Multilateration techniques for node localization in Wireless Sensor Networks. The proposed framework utilizes anchor node coordinates and corresponding distance measurements to estimate the positions of unknown sensor nodes. Localization is achieved through geometric computations and least-squares optimization methods, while graphical visualization tools are employed to illustrate the positioning process and facilitate performance analysis. The performance of both localization techniques is evaluated in terms of localization accuracy, estimation error, computational efficiency, and robustness against measurement uncertainties. Comparative simulation results demonstrate that Multilateration provides superior positioning accuracy and enhanced resilience to distance measurement errors compared with conventional Trilateration. The developed framework also serves as a valuable platform for investigating advanced localization algorithms and emerging positioning technologies.

The primary objectives of this research are to analyze localization requirements in Wireless Sensor Networks, implement Trilateration and Multilateration algorithms using MATLAB, evaluate their performance through simulation-based experimentation, and assess their suitability for practical WSN deployments. The outcomes of this study

contribute to the development of accurate, reliable, and scalable localization solutions and provide a foundation for future research involving optimization techniques, hybrid localization models, Artificial Intelligence (AI), and Machine Learning (ML)-based positioning systems for next-generation wireless sensor networks.

II. LITERATURE SURVEY

Wireless Sensor Network (WSN) localization has attracted considerable research attention due to its critical role in applications such as environmental monitoring, industrial automation, healthcare, military surveillance, and smart city systems. Accurate localization enables meaningful interpretation of sensed data and improves overall network efficiency.

Abdelhady Naguib [1] proposed a multilateration-based localization framework and compared atomic and iterative multilateration approaches. The study demonstrated that multilateration provides higher localization accuracy than trilateration by utilizing multiple anchor nodes. Similarly, Akhigbe-Mudu Thursday Ehis [2] introduced a Doppler-shift compensated multilateration technique incorporating Geometric Reference Triangulation (GRT), which significantly reduced localization errors while maintaining low computational complexity.

A comparative study on RSSI-based localization in LoRa networks [3] showed that multilateration achieved lower localization error compared to trilateration, highlighting its suitability for large-scale wireless sensor network deployments. Oguejiofor et al. [5] proposed an RSSI-based trilateration algorithm that achieved satisfactory localization accuracy with low implementation cost, making it suitable for static WSN environments.

Researchers have also investigated alternative range-based localization techniques such as Received Signal Strength Indicator (RSSI), Time of Arrival (ToA), Time Difference of Arrival (TDoA), and Angle of Arrival (AoA). While ToA and TDoA provide high positioning accuracy, they require strict synchronization and additional hardware support. AoA-based methods offer accurate localization but are sensitive to environmental interference and multipath propagation effects.

In addition to range-based approaches, range-free methods such as Centroid Localization, DV-Hop, and APIT have been widely explored due to their simplicity and energy efficiency. However, these methods generally suffer from lower localization accuracy. To address this limitation, hybrid and optimization-based techniques have emerged as promising alternatives. Suresh Sankaranarayanan et al. [6] developed a hybrid localization approach combining Crow Search Algorithm (CSA) and Weighted Centroid Localization (WCL), resulting in reduced localization error and improved energy efficiency.

The reviewed literature indicates that Multilateration generally provides better localization accuracy than Trilateration, particularly in the presence of measurement uncertainties. Furthermore, recent optimization-based and intelligent localization approaches offer significant potential for enhancing accuracy, robustness, and scalability in next-

III. SYSTEM DEVELOPMENT

System Overview

The proposed system is designed to simulate node localization in a Wireless Sensor Network (WSN) using MATLAB. The main objective of the system is to estimate the coordinates of unknown sensor nodes using the measured distances from anchor nodes with known positions. Localization is an important process in WSNs because sensor data becomes useful only when the exact physical location of the sensor node is identified. In the proposed system, anchor nodes are deployed with predefined coordinates, while unknown nodes are randomly placed within the sensing area. The distances between anchor nodes and unknown nodes are either generated synthetically or taken from stored datasets. Using these distance values, the system applies Trilateration and Multilateration algorithms to estimate the positions of unknown nodes. MATLAB is used for simulation, mathematical computation, and graphical visualization. The system also evaluates localization accuracy, computation efficiency, and the effect of anchor density on overall performance.

Components of the System

The proposed localization system consists of the following major components:

Anchor Nodes - Anchor nodes are sensor nodes with known coordinates. These nodes act as reference points for estimating the position of unknown nodes. The localization accuracy depends on the number and placement of anchor nodes.

Unknown Nodes - Unknown nodes are randomly deployed sensor nodes whose positions are not known initially. Their coordinates are estimated using distance information from anchor nodes.

Distance Data - Distance measurements between anchor nodes and unknown nodes are used as input for localization. In this project, the distance values are generated using datasets for simulation purposes.

The Euclidean distance formula is used for distance calculation:

System Functionality

The system estimates unknown node positions using geometric localization techniques.

Network Initialization - A two-dimensional network area is created in MATLAB where anchor nodes and unknown nodes are deployed.

Localization Process -

Trilateration is used when three anchor nodes are available.

Multilateration is used when four or more anchor nodes are available for improved accuracy.

Position Estimation - The system calculates the estimated coordinates of unknown nodes based on distance measurements.

Visualization -

MATLAB graphical tools are used to display:

Anchor nodes

Unknown nodes

Estimated positions

Network topology

MATLAB Implementation

Trilateration Implementation - Trilateration estimates the position of an unknown node using three anchor nodes. Each anchor forms a circular region, and the intersection point of the circles represents the estimated position of the unknown node. MATLAB performs the geometric calculations required for coordinate estimation. Multilateration improves localization accuracy by using four or more anchor nodes. The method applies least squares optimization to minimize localization error and determine the best estimated position. This method provides higher accuracy compared to Trilateration, especially when measurement noise is present.

Visualization of Results

MATLAB visualization tools are used to plot:

Anchor node positions

Actual unknown node positions

Estimated node positions

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

Different markers and colors are used for easy interpretation of localization results.

Performance Evaluation

Localization Accuracy - Localization accuracy is measured by comparing estimated coordinates with actual node positions. Lower localization error indicates better performance.

The localization error is calculated using:

$$LE = \sqrt{(x_{true} - x_{est})^2 + (y_{true} - y_{est})^2}$$

Computation Efficiency - Computation efficiency measures the time required by the localization algorithms.

Trilateration requires less computation time.

Multilateration requires slightly higher computation due to optimization calculations.

Effect of Anchor Density -Increasing the number of anchor nodes improves localization accuracy but also increases computation complexity. The system analyzes the impact of anchor density on localization performance.

Tools and Technologies

Software - The project is implemented using MATLAB software for simulation, computation, and visualization. Programming Language - MATLAB scripting language (.m files) is used for implementing localization algorithms. Input Data - The input data includes:

Anchor node coordinates

Distance measurements

Output Data - The output generated by the system includes:

Estimated coordinates

Localization error

Graphical visualization plots

Algorithms

4.5.1 Algorithm 1: Trilateration-Based Node Localization

To estimate the coordinates of an unknown node using the known positions of three anchor nodes and their measured distances.

Steps:

Start

1. Initialize the Wireless Sensor Network (WSN) environment in MATLAB.
2. Input the coordinates of three anchor nodes (A1, A2, A3).
3. Input the measured distances (r1, r2, r3) between the unknown node and each of the three anchor nodes.
4. Represent each anchor node as a circle, where:
Center = coordinates of anchor node
Radius = measured distance to the unknown node
5. Determine the point of intersection of the three circles — this intersection represents the estimated position of the unknown node.
6. Compute the estimated coordinates (x, y) of the unknown node using geometric relationships among the anchors and their distances.
7. Store the estimated coordinates in the system dataset.
8. Display the anchor nodes, distance circles, and the estimated position of the unknown node on the MATLAB plot.
9. Evaluate localization accuracy by comparing the estimated coordinates with the actual coordinates (if available).
10. Record the localization error and computation time for performance analysis.

End

4.5.2 Algorithm 2: Multilateration-Based Node Localization

To estimate the coordinates of an unknown node using the known positions of four or more anchor nodes, improving accuracy through optimization.

Steps:

Start

1. Initialize the Wireless Sensor Network (WSN) simulation in MATLAB.
2. Input the coordinates of four or more anchor nodes (A1, A2, A3, A4, ..., An).

3. Input the measured distances ($r_1, r_2, r_3, r_4, \dots, r_n$) between the unknown node and each anchor node.
4. Form distance relationships between each anchor node and the unknown node based on their geometric positions.
5. Use an iterative or optimization-based approach (such as least squares) to minimize the difference between the measured and estimated distances.
6. Estimate the coordinates (x, y) of the unknown node that minimize the overall distance error.
7. Store the estimated coordinates in the system dataset.
8. Visualize the network layout, showing anchor nodes and the estimated unknown node position.
9. Evaluate the localization accuracy using:

Localization Error (LE)

Computation Time

Effect of Anchor Density on accuracy

10. Display and record all results for analysis and performance comparison with trilateration.

End

IV. RESULTS

The proposed Wireless Sensor Network (WSN) localization system was successfully implemented and simulated in MATLAB using both Trilateration and Multilateration techniques. The simulation results demonstrate the effectiveness of geometric localization methods in estimating

the coordinates of unknown sensor nodes using anchor node information and distance measurements.

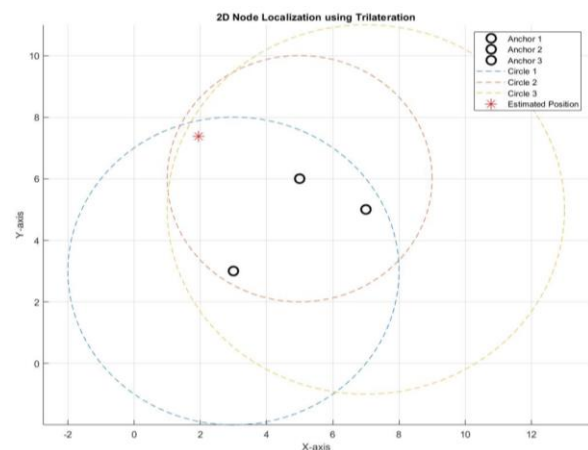
5.1 Trilateration Result Analysis - The first simulation was performed using the Trilateration technique, where three anchor nodes were used to estimate the position of a single unknown node. In this method, each anchor node generated a circular region centered at its known coordinates, with the radius equal to the measured distance between the anchor and the unknown node. The MATLAB visualization shows that the three circles intersect near a common region, and the estimated node position is represented by the red marker. The obtained result confirms that trilateration can successfully determine the approximate coordinates of the unknown node using only three reference anchors. The graphical output also demonstrates the geometric behavior of localization. Small deviations among circle intersections indicate the presence of minor estimation errors, which commonly occur due to imperfect distance measurements

or limited anchor coverage. Despite these deviations, the estimated position remains reasonably close to the actual node location.

The trilateration approach provides:

- Simple mathematical implementation
- Faster computation time
- Acceptable localization accuracy for small-scale networks

However, because only three anchors are considered, the localization accuracy is comparatively lower when measurement noise or irregular anchor placement exists.



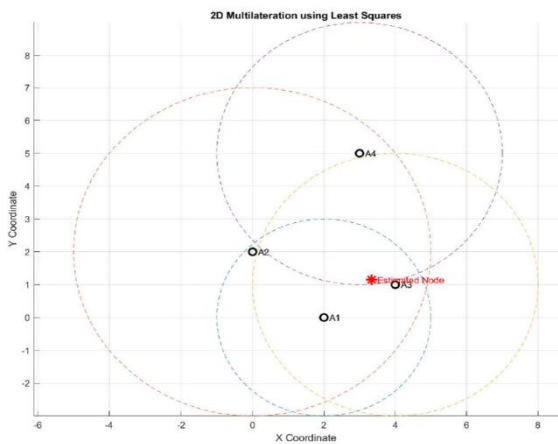
5.2 Multilateration Result Analysis - The second simulation implemented the Multilateration technique using five anchor nodes. Unlike trilateration, multilateration considers multiple anchor references simultaneously and applies a Least Squares Optimization method to minimize the cumulative localization error. The MATLAB plot illustrates multiple circular distance boundaries corresponding to different anchors. Since all circles do not intersect perfectly at one point, the optimization algorithm computes the best possible coordinate estimate that minimizes the total distance mismatch. The estimated node position obtained through multilateration is shown by the red marker in the graph. Compared to trilateration, the estimated position is more stable and mathematically optimized because additional anchor information improves the reliability of localization.

The results indicate that multilateration offers:

- Higher localization accuracy

- Better resistance to measurement noise
- Improved estimation stability
- Greater robustness in irregular network environments

The use of additional anchors significantly enhances coordinate estimation, especially in dense wireless sensor deployments.



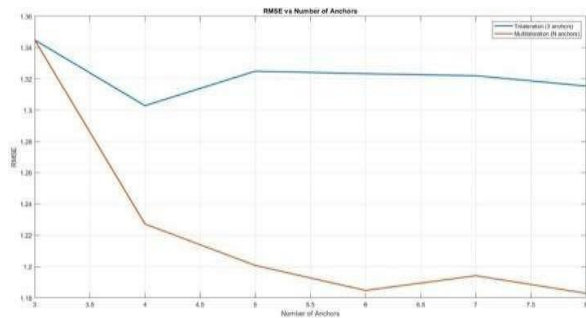
5.3 RMSE Performance Analysis - To evaluate the performance of both localization methods, Root Mean Square Error (RMSE) analysis was performed by varying the number of anchor nodes from 3 to 8. The generated graph clearly shows the relationship between anchor density and localization accuracy.

Observations from the RMSE Graph:

1. When only 3 anchors are used, both Trilateration and Multilateration exhibit nearly similar RMSE values, approximately 1.34.
2. As the number of anchors increases, the RMSE of Multilateration decreases significantly.
3. The minimum RMSE for Multilateration is observed near 8 anchors, reaching approximately 1.18.

4. Trilateration maintains relatively stable RMSE values around 1.30–1.32 because it fundamentally relies on only three anchors for computation.
5. Multilateration consistently outperforms Trilateration in terms of localization accuracy as anchor density increases.

The graph confirms that increasing the number of anchors improves localization precision because additional



geometric constraints reduce uncertainty in coordinate estimation.

V. CONCLUSION

This project presented a comprehensive study and implementation of node localization techniques in Wireless Sensor Networks (WSNs) using Trilateration and Multilateration methods. Accurate localization is a fundamental requirement for WSN applications, as the usefulness of sensed data largely depends on the precise geographical position of the sensor nodes. The proposed approach successfully demonstrated how anchor-node-based localization can estimate the positions of unknown sensor nodes with high accuracy while eliminating the need for GPS on every node, thereby reducing overall deployment cost and power consumption. The simulation results validated that Trilateration provides an efficient and computationally simple localization solution, whereas Multilateration significantly improves positioning accuracy and robustness by utilizing additional anchor nodes. The comparative analysis revealed that increasing the number of reference nodes reduces localization errors and enhances reliability, particularly in practical environments affected by measurement uncertainties and communication noise. These findings confirm the effectiveness of the proposed localization framework for large-scale and resource-constrained sensor network deployments.

Furthermore, the proposed system contributes to improved network performance by enabling accurate node tracking, efficient routing, optimized resource management, and reliable data interpretation. Such capabilities are essential for advanced applications including smart cities, environmental monitoring, industrial automation, healthcare systems, precision agriculture, disaster management, and defense surveillance. The MATLAB-based implementation provided a flexible platform for evaluating localization performance under varying network conditions and demonstrated the practical feasibility of the proposed methodology.

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