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Localization in Wireless Sensor Networks without Anchors within Square Topology

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***Abstract*—In the realm of wireless sensor networks (WSNs), the predominant focus lies on the precise tracking of positions. Despite the widespread acknowledgment of the importance of location data, the utilization of GPS devices within expansive sensor networks remains limited. This is primarily attributed to the considerable expense linked with GPS equipment and the extensive challenges posed by environmental conditions, which often obstruct the availability and reliability of GPS signals. Recognizing the essential of establishing node positions in the absence of GPS, we've introduced a novel localization algorithm tailored specifically for WSNs. Unlike conventional methods reliant on fixed anchor nodes, our approach circumvents this dependency. Instead, it leverages internode distances as the cornerstone of its localization strategy. By analyzing the average distance between neighboring nodes, our algorithm effectively determines the precise location of the reference node, offering a robust and cost-effective alternative to GPS-based positioning techniques within wireless sensor networks.**

***Index Terms*— Wireless Sensor Network, Node Localization, Energy Consumption, Triangulation, Optimization, Global Positioning System etc.**

I. INTRODUCTION

WSN operates without a predefined infrastructure, typically comprised of numerous sensors known as nodes, a controller unit, radio transceivers, and a power supply unit (usually batteries). These networks are typically deployed densely, either deterministically or randomly, to perform monitoring tasks in remote or inaccessible areas. WSNs find extensive application in various domains such as agriculture, water management, forest fire detection, pollution monitoring, military surveillance including battlefield reconnaissance and enemy detection, medical monitoring such as elderly care and health monitoring in livestock, and crisis management for events like earthquakes, floods, volcanic eruptions, and landslides.
Due to the absence of a centralized infrastructure to manage the network, the nodes themselves undertake the responsibility of routing and transmitting collected data to designated sinks, often base stations or coordinators. Localization emerges as a vital technique within WSNs, enabling the precise determination of the physical locations of sensor nodes
Localization of sensor nodes within a WSN stands as a main concern, as the meaningful interpretation of transmitted data or network events hinge upon knowledge of their precise locations. However, due to the deployment characteristics of sensors, localization methods often encounter inaccuracies, stemming from

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obstacles in the environment or fluctuations in signal strength as nodes transition between propagation environments. Moreover, the degree of connectivity exerts a notable influence; as connectivity decreases, localization accuracy tends to diminish, and conversely. Additionally, the energy expended by nodes during localization is directly proportional to the computational complexity and the volume of messages exchanged between nodes. Consequently, a delicate balance must be struck among coverage, positioning precision, energy consumption, and the level of connectivity.

That's a concise overview! Range-based localization methods typically rely on measuring distances or angles between nodes, often utilizing techniques such as triangulation or trilateration to estimate positions accurately. On the other hand, range-free localization methods use indirect measures like hop count or connectivity patterns to estimate relative positions without relying on precise distance measurements. Each approach has its own set of advantages and limitations, making them suitable for different scenarios and network configurations

It sounds like you've highlighted an important trade-off in sensor network design: the balance between positioning accuracy and cost. Indeed, increasing the number of anchor nodes can enhance accuracy, but it comes at the expense of higher hardware costs. Range-based techniques, while offering higher accuracy, often require specialized hardware, driving up deployment costs further.

On the other hand, range-free techniques can be more cost-effective since they don't rely on specialized hardware. Common examples like DV-Hop and DV-Hop Max WSNs leverage network connectivity information rather than precise distance measurements. This makes them more accessible for large-scale deployments where cost is a significant factor.

Ultimately, the choice between range-based and range-free techniques depends on the specific requirements of the application, including accuracy needs, budget constraints, and the scale of the sensor network deployment. It's often a matter of finding the right balance between accuracy and cost-effectiveness for the given scenario.

TABLE I. EVALUATION BETWEEN RANGE FREE LOCALIZATION AND RANGE BASED TECHNIQUES

Parameter	**Range Free Technique**	**Range Based Technique**
Power Consumption	Low	High
Supplementary Hardware	Not Required	Required
Level of Accuracy	Low (70%-75%)	High (85% -90%)
Employment	Easy	Hard/Complex
Toughness	Low	High
Efficiency	High	Low

This paper introduces a range-free node localization algorithm designed for single-hop WSNs. The algorithm relies on the average inter-node distance and utilizes RSSI values to gauge the distance between nodes. The subsequent sections of the paper are structured as follows: Section 2 reviews prior research in WSN localization, Section 3 outlines the metrics employed in the proposed algorithm, Section 4 details the proposed algorithms, Section 5 assesses the performance of the proposed algorithm, and Section 6 offers concluding remarks on the work presented in this paper.

II. LITERATURE REVIEW

Pandey et al.	[4]	a novel approach called the Hybrid Extendible Range-Based Distributed Cooperative Approach is introduced. The primary objective of this algorithm is to delve into and analyze the influence of Medium Access Control (MAC) protocols on the process of localization. By employing a hybrid and extendible methodology, the algorithm aims to offer a comprehensive understanding of how various MAC protocols affect the accuracy and efficiency of node localization in wireless sensor networks (WSN
Eva et al.	[5]	The paper introduces a bat algorithm tailored for Range-Based Localization, aiming to predict the positions of sensor nodes. The algorithm operates in two distinct stages: initially, four mobile beacons are strategically positioned at the periphery of the node-populated area to approximate sensor coordinates. Subsequently, in the second stage, these beacons adjust to their optimal positions with minimal distance from the sensor nodes. The proposed algorithm demonstrates enhanced applicability for systematic localization tasks
Thimmaiah et al.	[6]	In their efforts to minimize localization errors in WSNs, the researchers introduced a model named Adaptive Information Estimation Strategy Time of Arrival (AIES-TOA). They subsequently conducted a comparative analysis with Root Mean Square Standard (RMS-STD) across parameters such as localization error, error tolerance, and localization distance error.
Feng et al.	[7]	The primary emphasis of this paper lies in refining the localization technique, which predominantly

		relies on Received Signal Strength (RSS) measurements. In order to address small inaccuracies inherent in the data pertaining to node locations, the paper introduces the integration of a reference beacon node. This reference point serves to enhance the accuracy of the localization process by providing a stable and reliable benchmark for comparison. Moreover, to counteract deviations and anomalies within the Received Signal Strength Indicator (RSSI) Algorithm, the paper employs the Dixon Approach. This methodological framework aims to systematically identify and rectify inconsistencies in RSSI measurements, thereby contributing to the overall improvement of the localization accuracy within wireless sensor networks.
Ahmadi et al.	[8]	heir research focused on enhancing the minimum mean square error, thereby simplifying the computation of distances between source and destination nodes. Additionally, they took into account the hop counts and coverage radius between these nodes.
Prashar et al.	[10]	This article conducted a comparative assessment of various range-free techniques. Each technique was meticulously studied and compared based on localization error. The findings revealed a notable inverse. proportional relationship between the number of nodes and the range value.
Najeh et al.	[11]	An attempt to address the localization challenge led to the development of a novel range-free technique employing Genetic Algorithms (GAs). The authors employed Genetic Algorithms (GAs) in conjunction with the traditional DV hop technique to compute the position of unknown nodes.
Shahra et al.	[12]	This paper undertook a comparative analysis of two range-free localization algorithms, namely the Fingerprint and Centroid algorithms, utilizing Tmote sky devices. The authors meticulously assessed the performance of these algorithms in terms of localization accuracy and average error.
Yamei et al.	[13]	In this study, the authors introduced an enhanced iteration of the Distance Vector Hop (DV-Hop) technique. Their objective is to conserve energy by enabling only a single beacon node to broadcast its position information. Once the coordinates are estimated, the location error is diminished through the utilization of ratio positioning, thereby enhancing location accuracy.
Feick et al.	[14]	In the sensor node localization algorithm employing Genetic Algorithms (GA), parameters are referred to as genes [35, 36]. The genetic algorithm comprises three fundamental operations: selection, crossover, and mutation. Subsequently, a new generation is generated, and their fitness is evaluated using a fitness function. The new generation is then sorted from best to worst until convergence or reaching the predetermined number of iterations.
Lin L. et al.	[15]	The algorithm adjusts both the velocity and position of particles. Each particle explores two local optimal extremes and the entire population to identify the global optimal solution. The velocity and position of particles are updated based on predefined rules.
Cai S. et al.	[16,18]	A refined version of Voronoi diagram Based Localization (VBLS), named the weighted Voronoi diagram-based localization method, is introduced to determine the locations of nodes using RSS estimates. However, this approach struggles to accurately calculate distance estimates and suffers from improper selection of input parameters
Kumar A. et al.	[17, 18]	The author has introduced two distinct models for range-based models: Hybrid Particle Swarm Optimization and Biogeography-Based Optimization. These models offer innovative approaches to optimization within the context of range-based techniques.

Motivation: Anchor-free localization in Wireless Sensor Networks (WSNs) for square areas is a challenging yet crucial task for various applications, including environmental monitoring, surveillance, and asset tracking. Unlike traditional localization methods that rely on predefined anchor nodes with known locations, anchor-free approaches aim to determine the positions of all sensor nodes in the network without the need for such anchors. Here's an overview of anchor-free localization in a square area:

1. Network Initialization: In anchor-free localization, sensor nodes are typically randomly deployed within the square area, without prior knowledge of their positions or the presence of anchor nodes. Each sensor node is equipped with capabilities such as measuring distances or angles to neighboring nodes and exchanging information with them.

2. Connectivity-Based Techniques: One common approach to anchor-free localization is based on connectivity information exchanged between neighboring nodes. Nodes collaborate to construct a connectivity graph representing their spatial relationships. By analyzing this graph and employing techniques such as triangulation or trilateration, nodes estimate their relative positions within the square area.

3. Range-free Localization: Another approach is range-free localization, which doesn't rely on precise distance measurements but instead utilizes connectivity patterns or signal strength information to estimate node positions. Examples include DV-Hop, Centroid Localization, and Amorphous Localization algorithms, which estimate node positions based on hop counts, geometric centroids, or probabilistic models.
4. Collaborative Localization: In collaborative localization, nodes cooperate to collectively determine their positions. This may involve iterative algorithms where nodes refine their position estimates based on information exchanged with neighbors or distributed optimization techniques where nodes jointly optimize a cost function based on connectivity constraints.
5. Robustness and Accuracy: Anchor-free localization methods in square areas face challenges such as irregular node density, obstacles, and signal interference, which can affect localization accuracy. Robust algorithms capable of handling such challenges, as well as methods for mitigating localization errors, are essential for reliable localization in WSNs.
6. Energy Efficiency: Energy consumption is a critical consideration in WSNs, particularly for localization algorithms that involve communication and computation. Anchor-free localization algorithms should be designed to minimize energy consumption by optimizing communication overhead, reducing message exchanges, and employing energy-efficient algorithms.
7. Scalability: Scalability is another important aspect, especially for large-scale WSN deployments covering square areas. Anchor-free localization algorithms should scale gracefully with the size of the network, ensuring that localization accuracy and efficiency are maintained as the number of nodes increases.
8. Validation and Testing: Finally, anchor-free localization algorithms should be rigorously validated through simulations and real-world experiments to assess their performance in various scenarios, including different node densities, environmental conditions, and network topologies.
Overall, anchor-free localization in square areas presents unique challenges and opportunities for designing efficient and robust localization algorithms tailored to the specific requirements and constraints of Wireless Sensor Networks. By addressing these challenges, anchor-free localization methods can enable accurate and energy-efficient positioning of sensor nodes, unlocking the full potential of WSNs in diverse application domains.

Proposed Algorithm
Square Area Representation: The entire area in which the sensor nodes are deployed is represented as a square. This simplifies the geometric calculations involved in determining distances, coverage areas, and communication ranges between nodes.
Random Distribution of Nodes: Within this square area, the sensor nodes are randomly distributed. This randomness could be achieved through various means, such as random deployment by humans or algorithms that simulate random distribution.
Node Density: The number of sensor nodes, denoted by 'n', determines the density of nodes within the square area. Higher 'n' values indicate denser deployments with more nodes per unit area, while lower 'n' values indicate sparser deployments.
Communication and Connectivity: The algorithm likely considers how sensor nodes communicate with each other within this square topology. It may involve determining the optimal communication range for each node, ensuring that nodes within range can exchange information effectively while minimizing interference and energy consumption.
Coverage and Monitoring: Depending on the application, the algorithm may aim to optimize coverage and monitoring within the square area. This could involve strategies for efficient data collection, event detection, or area surveillance using the deployed sensor nodes.
Scalability: The algorithm might also consider how scalable it is within this square topology. As the number of nodes 'n' increases or decreases, the algorithm's performance and efficiency should ideally remain consistent or adapt accordingly
The principle of Received Signal Strength Indication (RSSI) ranging elucidates the correlation between the transmitted power and the received power of wireless signals, thereby providing insights into the distance between nodes.

$$\Pr = Pt \times (\frac{1}{d})^n \tag{1}$$

Where Pr is the received power of wireless signals, Pt is the transmitted power of wireless signal, d is the distance between the sending (TX) nodes and receiving (RX) nodes. and n is the transmission factor whose value depends on the propagation environment.

*(1) **Average distance of a node (D_{avg})***

If n number pf sensor nodes randomly deployed in a wireless topology at (x_1,y_1), (x_2,y_2), (x_3,y_3) and (x_n,y_n) with inter node distance as d_1, d_2, d_3….$d_n$respectively. Let distances between node i and other nodes be d_{i1}, d_{i2} ...din. Therefored_{ij}can be defined as –

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (2)$$

Centroid of the nodes can be calculated as-

$$C_x = \frac{\sum_{i=1}^{n} x_i}{n} \text{ and } C_y = \frac{\sum_{i=1}^{n} y_i}{n} \quad (3)$$

The average distance of a node (D_{avg}) among all distributed nodes will approximately equal to the distance from that node to the centroid of nodes (Dc). This D_{avg} for i^{th} node among n distributed nodes is defined as –

$$D_{avg} = \frac{\sum_{j=1}^{n} d_{ij}}{n-1} \qquad for \forall j; \qquad j \neq i \quad (4)$$

Normalized D_{avg} can be obtained by dividing maximum D_{avg} among all nodes to $D_{avg}$to particular node D_{avg}'is Given By-

$$D_{avg}' = \frac{D_{avg}}{(D_{avg})_{\max}} \quad (5)$$

In proposed anchor free localization this $D_{avg}$and internode distance is used to localize reference nodes first then for other nodes.

Algorithm for Single hop Localization

In a proposed algorithm that considers a square topology, it means that the area in which the sensor nodes operate is represented as a square. This topology choice simplifies certain aspects of the algorithm, as it allows for easier calculations and understanding of the node distribution and communication pattern

1: Every node transmits a beacon message containing its node ID according to its assigned TDMA schedule. Each node computes distances (dij), equal to (n-1), by measuring Received Signal Strength Indication (RSSI) from all other nodes using Equation (1).

2: The centroid of the nodes is determined using Equation (3).

3: In the subsequent step, all nodes compute the average distance, represented as Davg, using Equation (4).

4: Each node broadcasts its respective Davg, and the node with the highest Davg within the topology is identified as the furthest node from the centroid of the nodes, positioned at a corner of the topology as depicted in Figure 2 below. This node serves as the initial reference node for the system.

5: The second reference node is determined as the node farthest from the first reference node, situated as illustrated in Figure 3. This node consistently resides on the opposite side of node 1.

6: In this phase, the second reference node transmits the data regarding all distances d2j to the first reference node. Node 1 then computes the sum (d1j + d2j) for all nodes j where j ≠ 1, 2. The node with the highest value of this sum is identified as the one farthest from both the first and second reference nodes. This node serves as the third reference node for the system, as depicted in Figure 4

7: Using node 3 as a reference, identify the node furthest away; this will serve as the fourth reference node. Positioned in the opposite corner of node 3, as indicated in Figure 5, this node is established.

8: The node with the lowest Davg will possess the shortest distance from the centroid. Serving as the fifth reference node in our protocol, it will be positioned at the center of the topology, depicted in Figure 6, and function as the origin point for localization.

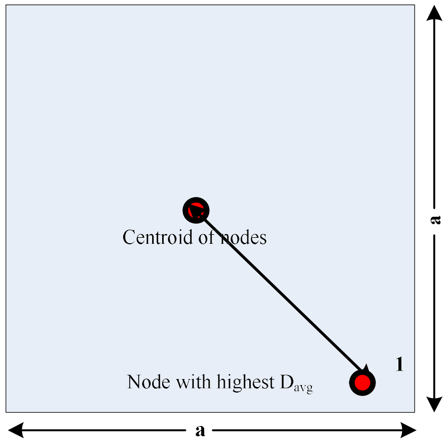

Fig. 2 First reference node

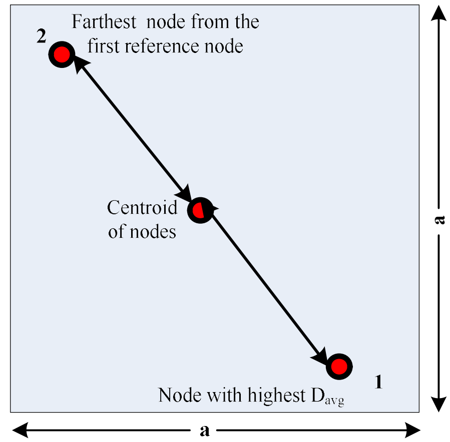

Fig. 3 Second reference node

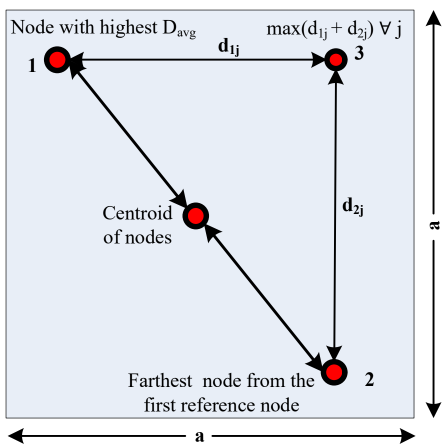

Fig. 4 Evaluation of Third reference node

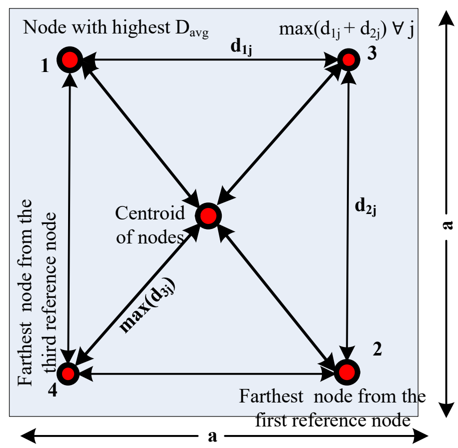

Fig. 5 Evaluation of fourth reference node

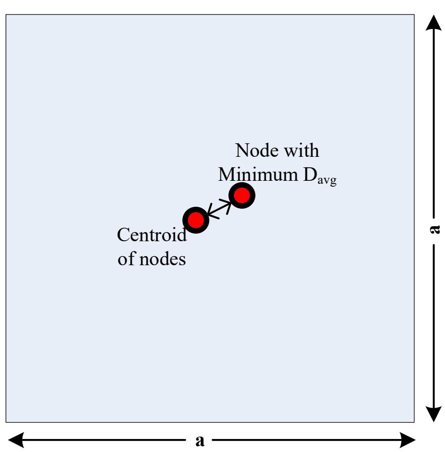

Fig. 6 Evaluation of fourth reference node

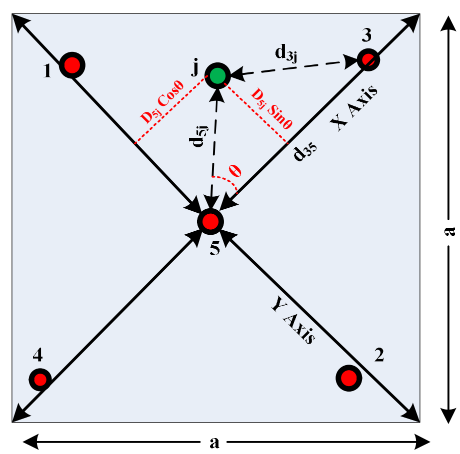

Fig. 7 Localization of node J

At present have computed five reference positions, the localization of the remaining nodes can be performed as follows. The origin is set at reference node 5. Relative to this reference node, the angles of different nodes are calculated for localization purposes. Reference node 3 is situated along the positive x-axis, while reference node 4 is positioned closer to the negative x-axis. Similarly, reference node 1 is positioned close to the positive y-axis, and reference node 2 is situated near the negative y-axis. Consequently, node j's localization within the topology can be achieved by estimating θ as depicted in Figure 7

$$Cos(\theta) = \frac{d^2_{53} + d^2_{5j} - d^2_{3j}}{2d_{53}.d_{5j}}$$

Thus node j is localized in topology depending quadrant in which the node is lying. For example if the node j is lying in 1st quadrant then coordinate for node j is given by

$$x = d_{5j}.Cos(\theta) \text{ and } y = d_{5j}.Sin(\theta)$$

Performance Analysis

Simulation was conducted using MATLAB, wherein a square field ranging from 100 m² to 500 m², incremented in steps of 100, and varying number of nodes from 100 to 250, incremented in steps of 50, was considered. The parameters utilized are outlined in Table 2. In the simulation design, the following constraints and assumptions were taken into account:

1. Nodes are placed randomly.
2. Each sensor node has an equal initial energy (E_0).
3. A node is considered dead if its energy falls below a threshold or if it is incapable of packet transmission and reception.

To estimate the localization error of the proposed algorithms, the same metric as presented in [22], Equation 8, was employed.

$$Error = \frac{1}{n}\sum_{i=1}^{n}\|ei - l_i\|$$

TABLE II. SIMULATION PARAMETERS

Parameters	**Values**
Number of sensor nodes (n)	100 to 250 with step size of 50
Network size	100 m² to 500 m² with step of 100
Number of sensor nodes (n)	100 to 250 with step size of 50
ϵ_{fs}(Amplification coefficient of free space signal)	10pJ/bit/m²
ϵ_{mp} (Multi-path fading signal amplification coefficient)	0.0013pJ/bit/m⁴
E_{elec}(Energy consumption in electronic circuitry.)	50nJ/bit
E_{DA} (Energy consumption in data aggregation at CH.)	5nJ/bit

Result Analysis

From the data illustrated in above Figure 8, it becomes evident that the average localization error diminishes as node densities increase, owing to the utilization of D_{avg} in the localization of reference nodes. While the initially proposed algorithm exhibits higher average error, as depicted, with the augmentation of node density in the topology, the proposed algorithm demonstrates the lowest average error.

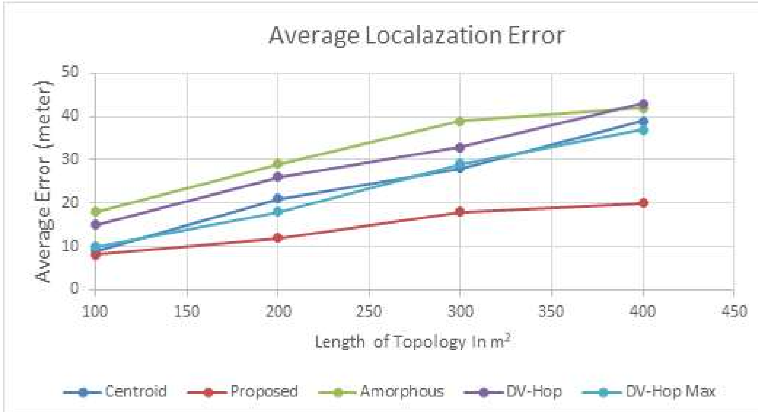

Figure 9 depicts the graphs illustrating the relationship between network topology size and average localization error for various communication ranges of sensor nodes. It is evident from the graph that as the network size increases, the average localization error also tends to increase. However, our proposed algorithm consistently exhibits the minimum error in comparison to other algorithms

Comparison of proposed and existing localization techniques is summarized [23] in table-3

TABLE III. COMPARISON OF PROPOSED AND EXISTING LOCALIZATION TECHNIQUES

Parameters	DV-Hop	Amorphous	APIT	DV-Hop Max	Proposed
Cost	Low	High	High	Low	Low
Scalability	Yes	No	No	Yes	Yes
Accuracy	Average	Average	Good	Goog	Excellent
Overhead	Low	High	High	Medium	Lowest

III. CONCLUSION

In this paper, we introduced anchor-free localization techniques designed for single-hop wireless sensor networks, relying solely on internode distance. Our proposed algorithm is both straightforward and efficient, particularly in terms of average localization error. We compared it with existing Centroid, Amorphous, APIT, DV-Hop, and DV-Hop Max Range algorithms. The results demonstrate that localization error diminishes with an increase in the number of nodes and topology area. Additionally, our newly proposed metric, Dave, exhibits notable performance in anchor-free scenarios.

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