Classification and Evaluation of Localization Techniques in Wireless Sensor Networks: A Comparative Analysis based on Performance Metrics

Omeed Kamal Khorsheed
Md Asri Bin Ngadi
Abdul Hanan Abdullah
Hamid Hantoosh Jebur

ABSTRACT
Although Wireless Sensor Networks have numerous applications, including monitoring health or the environment, military surveillance, industrial automation, and intelligent systems, nevertheless, there is hardly any clearly best technique for localization. Instead, each technique has its pros and cons that must be analysed regarding the particular needs of the application. This paper systematically catalogues the classification of techniques used for localization in WSNs, focusing on different local metric principles. Thereafter, every technique is studied and analysed exhaustively as regards their pros and cons. Moreover, a variety of quantitative indicators such as accuracy, complexity of implementation, cost, ease of use, trustworthiness, energy use, and extent of scalability are utilized for comparison. This analysis assists in elucidation the shortcomings and benefits of every technique and how they are valued in changing situations in diverse WSN applications. Moreover, the analysis outcome assists the practitioner and the researcher in selecting the appropriate localization technique.

Keywords
WSN, Localization, Classification, Performance Metrics, Comparison

1. INTRODUCTION
A Wireless Sensor Network (WSN) is normally known as a collection of distributed wireless sensor nodes, which are interconnected, creating the network backbone [1-3]. These sensors gather data from the target region, interact, and broadcast information to the final user [4][5]. The WSNs have gained substantial consideration in various fields including environmental monitoring, surveillance, healthcare, military, and intelligent systems [6-8]. Based on proper deployment methods, the network must collect data to enhance the decisions, thus the application and ambient determine this choice [9]. Optimization strategies and High-performance architectures are necessary for active WSNs management, [10]. A distinctive WSNs characteristic is the deploying capability of an immense nodes number within an area, achieving a complete coverage [11][12]. A sensor can be localized in a safe area based on a predetermined pattern [13] or deployed randomly based on common techniques in remote or unsafe areas by dropping sensors from above covering the target area [14]. Although a dense network offers many benefits, it can be plagued with problems such as node interference, failure of groups of nodes, or a reduced number of multi-hop paths in the network leading to isolate some of the non-failed nodes from the network [15]. These problems may lead to poor performance in converging the target area. Since localization is crucial to many applications, defining the node location in bi-dimensional or three-dimensional areas is compulsory to recognize the sensed data origin. Therefore, physical localization or attaching a GPS receiver to every node is one of the most techniques to identify sensor's locations in WSNs, however using a GPS is impracticable and highly cost [16-18]. In contrast, current developments in microelectromechanical systems (MEMS) lead to decrease the sensors size and cost, allowing deployment of large-scale WSNs [19], enabling effective monitoring of target area, and attaining the WSNs task [20].

2. FUNDAMENTALS OF NODE LOCALIZATION
WSN localisation uses anchors or beacon nodes to locate sensor nodes [16][21]. It is WSN's biggest difficulty because position information is necessary for area coverage, sensor deployment, and object tracking [8][22].

The main localisation difficulty is locating all or some sensor nodes [21]. One of the first steps in localisation is collecting position data using multiple techniques to calculate distance, angle, and hops between nodes or anchor nodes. The second phase estimates target node positions using data from the first phase. However, node self-localization, failure, and unknown node minimum location inaccuracy are localisation difficulties [16]. Creating low-cost, scalable, and efficient WSN localisation techniques is desirable. Numerous localisation methods have been proposed recently. Identification and data interchange, measurement and data capture, and device position computation comprise localisation methods [1]. However, these algorithms only estimate sites with error probability that reduces deployment efficiency [23]. Localisation methods still need help with localisation errors, scalability, mobility, position estimation, limited resources, time synchronisation across the source and all sensors, security, fault tolerance, and more [24][25].

3. CLASSIFICATION OF LOCALIZATION TECHNIQUES
WSN efficiency and efficacy depend on node localisation [21]. Traditional WSN localisation methods use connection, distance, and angle measurements to estimate node locations [26]. Application requirements including accuracy, cost, and complexity determine localisation technique selection. Mobile node mobility, energy consumption, anchor node movements, security, and wireless technology issues affect localisation strategies [21]. Thus, localisation strategies can be categorized using several criteria.

3.1. Classification Based on Accuracy Level
The classification of techniques in this category are based on the precision and accuracy of sensor nodes position estimation. The techniques include fine-grained and coarse-grained localizations, and the choice between them is based on

application-specific requirements. Fine-grained localization has higher precision but needs more resources. On the other hand, coarse-grained localization is less accurate but simple and energy-efficient [27][28].

3.1.1. *Fine-Grained Localization*

These localization techniques yield accurate node location information typically within centimeters or meters. They are expedient for applications that require accurate location information, such as individuals or objects tracking, making use of Triangulation or multilateration to calculate the nodes position based on measuring distance from several anchor nodes. They need more processing capability and energy consumption to perform their complex calculations.

3.1.2. *Coarse-Grained Localization*

These localization techniques yield less accurate location information, approximately within meters, but they can offer useful information about nodes localization area. They are more direct, cost-effective, and appropriate for applications that do not need accurate location information, like large zones monitoring or objects detection. Nodes use proximity-based algorithms and centroid localisation to calculate their position based on neighbouring anchor nodes' known locations.

Table 1. Advantages and Disadvantages of Localization Techniques Based on Accuracy Level

Category	Techniques	Advantages	Disadvantages
Fine-Grained	Triangulation or multilateration to estimate nodes position based on distance measurements from multiple anchor nodes	-High accuracy -Enables detailed spatial analysis -Flexibility -Suitable for critical applications - Support both 2D and 3D localization -Can handle complex network topologies and irregularities-	-Higher computational complexity -Increased power consumption -Sensitivity to measurement errors and noise -May involve extra costs such as need extra hardware or technologies -Limited scalability
Coarse-Grained	Use proximity-based methods and centroid localization	-Simpler to implement and require fewer resources -Lower computational complexity -Reduced power consumption -Cost-effective: do not need extra hardware or technologies -Scalability: can be easily scaled up to large-scale sensor networks -Less sensitive to measurement errors and noise	-Lower accuracy -Limited detail -Limited applicability scope suited for applications that do not need high accuracy or detailed -Sensitivity to environmental factors

Fine-grained techniques deliver high accuracy, flexibility and thorough spatial analysis, making them appropriate for critical applications such as 2D/3D localization and object tracking. However, they need higher computational power and consume more energy, moreover, they are sensitive to noise and errors making them more expensive and less scalable due to additional hardware requirements. On the other hand, coarse-grained techniques are cost-effective, simpler, scalable and energy-efficient, but they are less accuracy and less appropriate for applications requiring thorough location information.

3.2. Classification Based on The Infrastructure

The classification of Localization techniques in this category is based on the infrastructure (Topology). They include distributed (decentralized) and centralized techniques [29][30].

3.2.1. *Distributed Localization Techniques*

In these techniques nodes localize themselves based on their local information and coordination with nearby nodes without the central processing unit support [29][31]. The common distributed localization techniques are DV-Hop (Distance Vector-Hop), APIT (Approximate Point-In-Triangulation), Centroid Localization.

3.2.2. *Centralized Localization Techniques*

According to these techniques, a central processing unit or base station not only gathers data from nodes, but also performs the localization computation and then communicates the position information back to the nodes. These techniques are characterized by higher computational complexity, making them unsuitable for large-scale sensor networks. The standard centralized localization techniques are RSSI (Received Signal Strength Indicator), Least Squares Estimation (LSE), Global Positioning System (GPS)-based, Multi-Dimensional Scaling, linear programming and stochastic optimization algorithm [1][31][32][33]. Table 1 lists localization-based structural pros and cons [1][29][30][31][32][34][35][36][37]:

Table 2. Advantages and Disadvantages of Localization Techniques Based on Infrastructure

Category	Techniques	Advantages	Disadvantages
Centralized	The central base station performs all the operations	-Good accuracy (more accurate estimation results) -Deploy ability is hard -No additional hardware -Less computing cost -More feasible for small-scale systems -Easy to implement -Reduced communication overhead	-Single point of failure -More time delay and traffic congestion -No scalability -High communication cost -Limited scalability in large networks -Lack of flexibility -Higher power consumption
Distributed	Each node is responsible for position estimation and exchanges the data with anchor nodes	-Good scalability -Reduces traffic congestion -No single point of failure -Easily implemented -Less power consumption -Flexibility -Robustness against node failures -High privacy and security	-The localisation error is large -No concept of shortest path for inter-node communication, leading to a decrease in throughput--Additional hardware is required -Lower accuracy compared to centralized approaches -Sensitivity to noise and interference

Compared with distributed algorithms, centralized algorithms produce more precise results, easy to implement for small-scale systems without requiring additional hardware. However, they suffer from single failure points, scalability matters, higher communication costs, and lack flexibility in large networks. On the other hand, distributed systems are more vigorous than centralized systems, such as fewer possible link failures [38], scalable, energy-efficient and provide high privacy and security. However, they are disposed to to larger localization errors, need extra hardware and are sensitive to interference and noise.

3.3. Classification Based on Anchor-node

These techniques depend on the presence / absence of the anchor node, known as anchor-based techniques. They include anchor-based and anchor-free techniques. This classification can be employed in distributed and centralized localization techniques [29][31][34][40].

3.3.1. *Anchor-Based Techniques*

Anchor-based techniques employ fixed anchor nodes with specific positions to calculate the unknown nodes positions in the WSN.

3.3.2. *Anchor-Free Techniques*

These techniques calculate the unknown nodes positions relative to one another, by producing a comparative coordinate system.

Table 3. Advantages and Disadvantages of Anchor Node Localization Techniques

Category	Techniques	Advantages	Disadvantages
Anchor-based	Using known reference points to provide accurate positioning	-High localization accuracy -Simple, effective -Easy to implement -Collaboration and communication -Robustness	-Scalability problem (low deployment flexibility) -Network flooding (Need dense network of anchor nodes) -Mobility problem -Limited indoor performance -Dependency on anchor nodes -Lack of flexibility
Anchor-Free	Determine sensor node location by their communication with the other nodes	-No need for additional infrastructure and pre-defined reference points -Lower communication cost -Flexibility -Easy deployment	-Mobility problem -Less accuracy -Require higher node density to achieve similar location -Sensitivity to noise -Scalability challenges

Anchor-based techniques utilize fixed reference points to attain high accuracy, robustness, and ease of implementation, making them appropriate for applications demanding accurate positioning. However, they suffer from scalability matters, mobility challenges, network flooding, and dependance on anchor nodes, which limits their flexibility. on the other hand, anchor-free techniques are flexible, cost-effective and easy to deploy without needing predefined reference points, but they are less accurate, need higher node density and face scalability issues and noise sensitivity. In comparison with anchor-base techniques, anchor-free Anchor-techniques are less restrictive, having less convergence time and relative node positioning [41]. Anchor-based techniques fall in the category of range-based localization as they use precise distance or angle measurements from known anchors.

3.4. Classification Based on Distance Measurement

Based on transmission method or distance measurement, node localisation approaches are range-free or range-based [26][35][42][43][44]. The both techniques can also be categorized under centralized and distributed localizations within WSNs [32]. Hybridization of diverse range-based techniques is a recognized approach for localization that attains good coverage and accuracy [32].

3.4.1. Range-Based Techniques:

In these techniques, the physical distance between nodes employing diverse signal properties is measured [1][21][31][32][45][46][47][48][49][51]. Radio frequency (RF) signal in these techniques is used for localization and node communication. The regular techniques to measure the range are:

3.4.1.1. RSSI (Received Signal Strength Indicator)

This method is common in WSNs. Signal power quality at the receiver estimates transmitter-receiver distance. distance-related loss.

3.4.1.2. ToA (Time of Arrival)

This method estimates the distance between anchor or reference nodes and unknown nodes using signal travel time. To calculate the receiving and transmitting nodes' distance, it measures the signal's one-way propagation time. This approach requires accurate time synchronisation between nodes and timestamp information in various packets.

3.4.1.3. TDoA (Time Difference of Arrival)

This method calculates the difference in arrival times of simultaneous signals from the same source. Time synchronisation between transmitting nodes is required in TDoA. TDoA improves positioning accuracy in large transmitting node deployments.

3.4.1.4. AoA (Angle of Arrival):

This technique specifies the direction from which a signal is received to measure the position. This process requires specific hardware like antenna array. Accuracy is, however, dependent on bandwidth and size and direction of the antenna.

Table 4. Advantages and Disadvantages of Range-Based Localization Techniques

Category	Techniques	Advantages	Disadvantages
RSSI	Measure the RSS between a transmitter and receiver	-It's easy to implement -Not sensitive to timing and RF bandwidth -Most widely used -Difficult to scale	-impacted by environmental factors -Less accurate than others (Accuracy decreases with distance) - Affected by Near-line-of-sight (NLOS) conditions -Not suitable for large-scale deployments
ToA	Uses the signal travel time	-Accurate compared to the RSSI -Easy to implement	-Needs accurate time synchronization between nodes -Additional hardware may be required - Biased from the environment -High-cost of implementation -Complex
TDoA	Measures the difference in transmitted signals arrival times	-More accurate than ToA -It can be utilized with different communication technologies, i.e., ultrasound and RF -Difficult to scale	-Needs accurate time synchronization between transmitting nodes -Performance is degraded in the NLoS signal propagation -Complex
AoA	Determines the direction of the received signal	-Can provide high localization accuracy -No time synchronization between the nodes is needed - Difficult to scale	-Extra hardware is required (e.g., antenna arrays) -Expensive computational cost -Affected by multipath and fading -Accuracy is affected by nodes' density -Complex

Range-based techniques provide high accuracy and appropriate for small to medium-sized networks, but they consume more energy, expensive, need specific hardware, and are vulnerable to environmental interference, restraining their scalability. Range-free techniques are energy-efficient, more cost-effective, and ease of implementation, making them perfect for large-scale networks. However, they offer lower accuracy and are highly reliant on node density for operative localization.

3.4.2. Range-Free Techniques:

These Techniques do not use direct distance measurements but rather infer relative positions based on connectivity and network topology [21][31][46][47][48][50][52]. These techniques include:

3.4.2.1. DV-Hop (Distance Vector-Hop):

Hop count and average hop distance are used to indirectly determine distances. Others use node location and hop count to determine distances.

3.4.2.2. Centroid Localization technique

calculates node positions based on the centroid of the positions of adjacent anchor nodes. What is characteristic about this technique is that it uses a proximity-based localization approach, where multiple anchor nodes broadcast their coordinates to facilitate node localization.

3.4.2.3. APIT (Approximate Point-in-Triangulation Test)

It is a non-ranging-based approach that uses overlapping communication ranges of anchor nodes (Uses triangular regions formed by anchor nodes) to determine node positions. Nodes determine their position by checking if they fall within the overlapping areas of triangles formed by three anchor nodes. The system assumes all WSN nodes in a given area send data. High density and communication range are sacrificed for high precision by approximation.

Table 5. Advantages and Disadvantages of Range-Free Techniques Localization Techniques

Category	Techniques	Advantages	Disadvantages
DV-Hop	Uses the count hop between nodes	-Simple -Doesn't require additional hardware -Low accuracy - Easy to scale	-Less accurate in scattered networks. - Prone to distance estimation errors due to obstacles between sensor nodes
Centroid	Uses the centroid of the positions of nearby anchor	-Easy to implement - Easy to scale -Low accuracy	-Accuracy influenced by environmental propagation conditions - Accuracy affected by density and distribution of nodes
APIT	Uses the communication ranges overlap of anchor nodes	-Achieves balance between complexity and accuracy - Easy to scale	- Needs high network connectivity -Less accuracy compared to range-based schemes

DV-Hop is scalable, simple and does not need extra hardware, but it has lesser accuracy in scattered networks and is disposed to distance estimation errors. Centroid localization is scalable, and easy to implement, but its accuracy is affected by node density and environmental circumstances. APIT is scalable, balances accuracy and complexity, but it needs high network connectivity and has less accuracy compared to range-based techniques. In general, the advantages and disadvantages of localization techniques based on distance measurement are identified in Table 4 [32][44][46][47].

Table 6. Advantages and Disadvantages of Localization Techniques based on Distance Measurement

Category	Techniques	Advantages	Disadvantages
Range-Based Techniques	Using radio frequency signals for communication between nodes	-High accuracy -High cost -Good for small to medium-sized networks	-High cost -Susceptible to environmental interference -Requires extra hardware and consumes more energy -Limited scalability
Range-Free Techniques	Using connectivity and network topology to Conclude relative positions	-Lower cost -Energy efficient -Easier to implement -Scalable	-Lower accuracy -Dependent on node density

Range-based techniques generally offer higher precision but are possibly affected by noise, fading, and the need for specialized hardware. Range-free techniques are usually less accurate than range-based techniques but are more cost-effective and more accessible to implement. It is meaningful to note that the advantages and limitations mentioned above are only general characteristics and may deviate depending on the specific algorithms and techniques used within the range-based and range-free localization techniques [46]. Method selection depends on deployment criteria including accuracy, environment, and resources.

3.5. Classification Based on Position Calculation

Position calculation techniques in WSNs are essential in determining the exact location of sensor nodes. In these techniques, the unknown nodes count their positions relative to the anchor nodes using estimated distances or connectivity information. Common techniques include [31][40][45][53][54][55]:

3.5.1. Lateration

here, the node position is figured by measuring the distances between the node and multiple anchor nodes with known positions. This method commonly uses range-based techniques (ToA, TDoA, RSSI). Two types of Lateration:

3.5.2. Trilateration:

This technique utilizes the distances between three or more anchor nodes to determine a node's position. Trilateration is a typically used as a cost-effective method that determines locations in wireless sensor networks. However, its accuracy is highly reliant on the precision of the range measurements and the placement of the reference nodes.

3.5.3. Multilateration:

It is an extension of trilateration that uses more than three anchors for improved accuracy.

3.5.4. *Triangulation*:

This technique uses angle measurements from multiple anchors to determine the node's position. It makes use of the angles between the unknown node and two or more anchor nodes to determine the position.

3.5.5. Angulation (Angle of Arrival):

Here, the position of a node is obtained based on the intersection of angles of the arriving signals from known anchor nodes. Consequently, directional antennas or an array of antennas is required to measure the angle of incoming signals.

Table 7. Advantages and Disadvantages of Localization Techniques based on Position Calculation

Category	Techniques	Advantages	Disadvantages
Lateration	Node position is calculated by the distances between the node and multiple anchor nodes	-Simpler -Less expensive compared to angulation -High accuracy	-Accuracy affected by environmental factors like signal attenuation and multipath effects -Needs accurate distance measurement -Requires sufficient number of reference nodes
Triangulation	Angle measurements from multiple anchors used to determine the node's position	-Provides good accuracy in line-of-sight conditions. -Effective in scenarios where angle measurements are more reliable than distance measurements -Low cost	-Performance can degrade with multipath propagation and in non-line-of-sight conditions -Requires directional antennas or arrays to measure angles accurately.
Angulation	Node position is calculated based on the intersection of angles of the arriving signals from known anchor nodes	High accuracy in environments with clear line-of-sight -No time synchronization is required	-Needs expensive hardware to measure the angles (antenna) -Effective in scenarios where distance measurement is difficult

Lateration is cost-effective, simple, and offers high accuracy, but influenced by environmental conditions, needs precise distance measurements, and adequate reference nodes.

Triangulation is active in line-of-sight conditions and provides good accuracy at a low cost, but non-line-of-sight circumstances affect its performance and it needs directional antennas for precise angle measurements. Angulation offers high accuracy without needing time synchronization, but it requires costly hardware like antenna arrays and is influenced by signal interference and complexity.

3.6. Classification Based on Dimensionality

The classification of 2D vs. 3D localization in WSNs can be considered as a further categorization dimension that overlaps with centralized and distributed techniques [26][51][56].

3.6.1. 2D Localization

This technique involves determining the position of sensor nodes in a two-dimensional plane, which makes it uncomplicated and less computationally demanding compared to 3D localization. Several localization algorithms including fine or approximate, centralized or distributed are viable in a 2D setting.

3.6.2. 3D Localization:

It adds third dimension like height or depth of sensor nodes, making it applicable for more complex setting like underwater, forests, or urban areas. This localization requires more calculations and advanced algorithms.

Table 8. Advantages and Disadvantages of Localization Techniques based on Dimensionality

Category	Techniques	Advantages	Disadvantages
2D	All nodes deployed on a plain field ignoring nodes Altitude information	-Easy to implement -Requires fewer sensors and infrastructure compared to 3D systems. -Cost-effective -Compatibility: 2D systems integrated easily with existing technologies (GPS, Wi-Fi)	-The location information is provided in two dimensions increasing the challenges for complex indoor settings. -Incomplete representation: may not give exact representation of the true position of an entity. -Lower accuracy than 3D systems.
3D	Altitude information is considered on the deployment field	-More accurate -Enables better and accurate navigation, tracking, and interaction within the environment -Enables new applications that require precise vertical positioning	-More complicated compared to 2D systems. It may entail extra infrastructure, sensors, and algorithms -More costly -May not broadly adopted as 2D technologies -Possibility of signal interference may affect reliability or accuracy.

2D localization is cost-effective, simple, and requires less infrastructure and sensors, making it appropriate for modest applications. However, it offers imperfect representation in complex indoor settings and provides less accuracy than 3D systems. 3D localization provides better accuracy and allows accurate tracking and navigation in complex situations, but it is costly, needs more computational demanding, and disposed to signal interference, making it less broadly adopted than 2D systems.

3.7. Classification of Localization Techniques Based on Node Mobility

Localization techniques are categorized according to node mobility into static and mobile localizations [34][57].

3.7.1. Static Localization Techniques:

These methods use fixed anchor nodes to calculate sensor node locations. Since the anchor nodes have established coordinates, they can be used to calculate the unknown sensor node's location using angle or distance measurements. These methods are suitable for relatively stable environments with immovable sensor nodes.

3.7.2. Mobile Localization Techniques:

These techniques locate static or mobile sensor nodes using mobile anchor nodes. Sometimes mobile anchors send beacons with their coordinates for sensor nodes to locate them. These techniques extend coverage and adaptability in dynamic environments. There are, however, hardships associated with them, such as anchor trajectory planning, node density, noisy measurements, and resource constraints. Most applications utilize static nodes because some sensors are static in nature. Few applications employ mobile sensor nodes, requiring special localization techniques.

Table 9. Advantages and Disadvantages of Localization Techniques based on Node Mobility

Category	Techniques	Advantages	Disadvantages
Static Localization Techniques	Determines the sensor node's locations using the fixed anchor nodes' information	-Higher accuracy in determining the position of nodes -Lower power consumption due to stationary anchor nodes -Easier deployment as anchor nodes can be placed in predetermined locations -Cost-effectiveness where specialized hardware is not required -Suitable for static environments	-Limited coverage as anchor nodes are fixed and cannot cover a large area -Lack of adaptability to changes in the environment or movement of objects -Dependency on anchor placement -Vulnerability to node failures
Mobile Localization Techniques	Uses mobile anchor nodes to estimate the locations of static or mobile sensor nodes	-High coverage as anchor nodes can move with the objects being localized -Flexibility and adaptability to changes in the environment or the movement of objects -Real-time tracking of objects -Probability of redundancy when multiple mobile anchors are used -Improved accuracy	-Lower accuracy compared to static methods due to the movement of anchor nodes and objects being localized. -Higher power consumption as anchor nodes need to move and communicate with each other. -Complex deployment requiring careful planning and coordination of the anchor node movement and communication -Higher implementation cost where specialized hardware may be required -Complexity

Static techniques utilize fixed anchor nodes, offering high accuracy, inexpensive and lesser power consumption, however, they have imperfect coverage, lack adaptability, and are susceptible to node failures. Mobile localization techniques use mobile anchor nodes, providing more coverage, real-time tracking and flexibility, however, they provide less accuracy, more energy consumption. Moreover, they need complex deployment and higher costs of implementation.

Each of the static and mobile localization is classified into two categories as introduced in the following [45][57][58]:

3.7.2.1. Static anchors and static sensors-based techniques

Static sensors and anchors are used. Advanced and reliable, they outperform other categories. Position information of a few static anchors and inter-sensor metrics like distance and connectivity are used to locate static unknown sensors. This category comprises range-based and range-free schemes.

3.7.2.2. Static anchors and mobile sensors-based techniques

These strategies allow nodes to move with anchors in predefined locations. Mobile sensors are localized using a few static anchors. The anchor node's signals let an unknown mobile sensor locate itself.

3.7.2.3. *Mobile anchors and static sensors based-techniques*

These techniques localize static sensors using a few moving anchors. Most use one or two moveable anchors. This movable landmark or anchor moves through a sensing region and sends beacon messages for location calculation.

3.7.2.4. Mobile anchors and mobile sensors based-techniques

These methods localize mobile sensors using mobile anchors. Anchors communicate coordinates occasionally as they travel around the deployment region. Anchors help unknown sensors approximate their placements.

Table 10. Advantages and Disadvantages of static and mobile localization techniques Types

Category	Techniques	Advantages	Disadvantages
Static anchors and static sensors-based techniques	Both sensors and anchors are static	-Extensively studied and developed -High accuracy -Cost-effective: no specialized hardware -Suitable for static environments	-Limited coverage -May not be suitable for dynamic environments -Dependency on anchor placement -Vulnerability to node failures
Static anchors and mobile sensors-based techniques	Nodes have mobility, and anchors are placed in pre-defined locations	-Flexibility -Extended coverage -Improved accuracy -Can provide redundancy in the localization system	-Increased energy consumption -Higher implementation -Complex to design and implement compared to static localization cost -Localization delay
Mobile anchors and static sensors based-techniques	One or two mobile anchors localise static sensors.	-Reduced cost -Flexibility -Improved accuracy -Suited for specific applications such as military operations or forest fire detection	-Need proper planning of anchor trajectories -Accuracy depends on the density of sensor nodes -Flexibility and adaptability: can introduce noise in the measurements
Mobile anchors and mobile sensors based-techniques	Mobile anchors locate mobile sensors.	-Can provide adaptability in dynamic environments -Extended coverage -Improved accuracy -Cost-effective: Using mobile anchors instead of GPS-enabled devices	-Consume more energy -Higher implementation cost: may require specialized hardware -More complex to design and implement -Probability of errors in localization due to signal interference

Static anchors with static sensors are inexpensive, highly accurate and but have imperfect coverage and are inappropriate for dynamic environments. Static anchors with mobile sensors enhance accuracy and coverage but rise complexity and energy consumption. Mobile anchors with static sensors decrease costs and enhance flexibility but need anchor trajectories careful planning and are sensitive to node density. Mobile anchors with mobile sensors offer adaptability and more coverage but are costly, consume more energy and disposed to errors due to signal interference.

3.8. Classification of Localization Techniques Based on Localization Environments or Deployment Scenarios

Localization techniques designed for indoors and outdoors are dedicated to specific challenges and requirements. Indoor localization must address obstacles like walls and furniture, while outdoor localization contends with weather conditions and terrain factors. It is understanding the significance of indoor and outdoor localization techniques that really helps optimize network performance, ensuring reliable data collection and enhancing the effectiveness of WSN deployments in diverse settings [56][57].

3.8.1. Indoor localization techniques

are associated with determining the position of movable or fixed objects within an indoor environment, such as a building or a room. They employ diverse technologies to correctly track and recognize the object's location in areas like underground parking lots or shopping malls where GPS signals are either unreliable or inaccessible.

3.8.2. Outdoor localization

refers to locating an object or device outside in an open environment, such as a street or field. It relies on satellite-based systems like GPS for accurate position calculation. Outdoor localization is commonly used in navigation systems, mapping applications, and outdoor tracking scenarios. They take advantage from the availability of clear line-of-sight to satellites and fewer obstacles that can interfere with signal reception.

Table 11. Advantages and Disadvantages of Indoor/Outdoor localization techniques

Category	Techniques	Advantages	Disadvantages
Indoor	Range based or range free	-Higher accuracy -Better coverage in smaller areas -Cost-effective implementation using existing infrastructure and devices -Reduced interference from external sources -Better privacy and security compared to outdoor -Can be carried out using various technologies, such as Wi-Fi, Bluetooth, RFID, ZigBee, and cellular networks -Enables precise tracking and positioning of objects within a confined space	-Limited scalability to larger areas or outdoor environments -Higher implementation cost -Limited applicability to outdoor applications. -Partial coverage -Deployment process is complex -Affected by environmental challenges such as signal interference, multipath effects, and obstacles.
Outdoor	Range based or range free	-Wide coverage for large areas. -Lower cost due to reliance on existing infrastructure. -Availability of signals in outdoor environments. -Scalability to cover larger areas. -Accurate distance estimation -No clock synchronization needed	-Lower accuracy compared to indoor techniques. -Vulnerability to environmental conditions. -Limited availability of infrastructure in remote areas. -Privacy issues with GPS or cellular-based techniques

Indoor techniques offer high accuracy, better coverage in limited spaces, and improved security and privacy, making them appropriate for surroundings like malls or buildings. However, they have limited scalability, higher costs of implementation, and are influenced by environmental issues like obstacles and signal interference. Outdoor techniques provide inclusive coverage, scalability, lower costs, and precise distance estimation, making them perfect for open environments like fields or streets. However, they offer less accuracy than indoor techniques, prone to environmental circumstances, and face privacy issues in GPS or cellular-based systems.

4. PERFORMANCE METRICS AND EVALUATION

Performance evaluation of localization techniques is a vital aspect for researchers to select the most suitable one for a certain WSN application based on its constraints and necessities. Thus, researchers should designate relevant evaluation metrics or performance criteria for comparison to assist users and developers in understanding application needs. The performance evaluation metrics comprise coverage, localization accuracy, cost, robustness, complexity, and scalability. These criteria consider and address restrictions such as power consumption, network scalability, unit cost, and computational complexity. [1][32].

4.1. *Accuracy*
The precise estimation of node positions is the aim of localization techniques. The target position accuracy differs by application, with satisfactory error depending on inter-node spacing. A decent localization technique should keep accuracy in spite of inadequate input data and noise, confirming vigorous performance in real-world deployment settings.

4.2. *Cost*
The cost for the localization procedure, such as communication overhead, power consumption, and pre-deployment cost should be considered (e.g., number of required anchor nodes). Minimizing these costs is vital for prolonging network lifetime.

4.3. *Coverage*
The coverage signifies how well the sensors monitor the whole interested area where they are deployed. It is the performance measure of the network sensing capability. The technique should place optimally the sensor nodes within the network, ensuring coverage quality and minimizing coverage holes.

4.4. *Topologies*
Network topology has a significant effect on WSN performance, localization accuracy, scalability, reliability, and energy efficiency.

4.5. *Scalability*
Scalability is the network's ability to effectively function and maintain performance as the sensor nodes number increases. As WSNs can contain lots of nodes, the localization technique must be scaled up to large-scale sensor networks without significant performance degradation.

4.6. *Computational Complexity*
Localization techniques are complex in terms of software and hardware. The localization technique must be fast when computing the sensor position information because computation consumes energy, and sensors' battery lives are short.

4.7. *Complexity*
The localization technique complexity is relative to the hardware and software required to function efficiently. The complexity of a WSN localization technique influences the network's performance, deployment, as well as maintenance.

4.8. *Precision*
Precision is a metric of a measurement's repeatability; if the findings are repeatable accurately, the measurements are precise.

4.9. *Stability*
The localization technique functions efficiently and steadily, providing accurate and reliable position estimates over time even in changing environments,

4.10. *Reliability*
It refers to the possibility of a localization technique providing exact and error-free location information at a specific place and time. It evaluates the system's reliability in delivering correct feedback, even in challenging environments.

4.11. *Robustness*
The technique shows ability to maintain performance despite changes in the environment or network conditions.

4.12. *Latency*
The time taken for localization of all nodes in the network. Long localization processes may result in data to be outdated, increase energy consumption, increase communication overhead, leading to synchronization issues within the network. Minimizing latency is crucial for maintaining performance and efficiency.

4.13. *Deployability*
It is an important performance metric for localization techniques in WSNs, assessing the simplicity and feasibility of implementing and maintaining the localization technique in real-world scenarios.

5. TECHNIQUES COMPARISON
Evaluation metrics help researchers assess their methods, compare them to others, and choose the best ones for specific applications. The following Table compares localisation strategies based on their pros and cons.

Table 12. Comparison of Localization Techniques

Localization Technique	Accuracy	Cost	Energy Efficiency	Extra Hardware	Deployability	Reliability	Scalability	Complexity
Fine-Grained	high	high	low	yes	high	high	medium	high
Coarse-Grained	medium	low	high	no	low	medium	high	low
Distributed	Variable[1]	medium	Variable[2]	yes	medium	high	high	high
Centralized	high	medium	Variable[3]	no	Variable[4]	medium	medium	medium
Anchor-Based	high	medium	medium	yes	high	high	medium	medium
Anchor-Free	medium	low	high	no	low	medium	high	high
Range-based	high	medium	medium	yes	high	high	medium	high
Range-free	medium	low	high	no	low	medium	high	low
Lateration	high	medium	medium	no	high	high	medium	high
Triangulation	high	medium	medium	yes	high	high	medium	high
Angulation	high	high	low	yes	high	high	medium	high
2D	high	medium	medium	yes: less	medium	high	medium	medium
3D	very high	high	low	yes: more	high	high	medium	High
Static	high	medium	high	no	low	high	medium	medium
Mobile	medium to high	high	low	yes	high	medium	medium	High
Indoor	high	high	Variable[5]	yes	low	Variable[7]	medium	high
Outdoor	lower	low	Variable[6]	yes less	medium	high	high	medium

Variable[1]: High if nodes collaborate effectively. Low due to errors
Variable[2]: Efficient if optimized. Excessive communication and computation affect battery life
Variable[3]: High for nodes. Low for central unit
Variable[4]: Low for nodes. High for central unit
Variable[5]: high-accuracy methods may consume more power
Variable[6]: GPS can be power-hungry
Variable[7]: affected by environmental factors but reliable with proper setup

Researchers must balance performance metrics, application requirements, environmental constraints, and cost considerations when selecting localization techniques. Reviewing case studies and pilot tests should also be conducted to provide insight into a technique's correctness.

To visualize the main metrics (accuracy, cost, and energy) we converted their qualitative levels into the following numeric scale to simplify the visualization:
Very High = 4
High = 3
Medium / Variable = 2
Low / Lower = 1

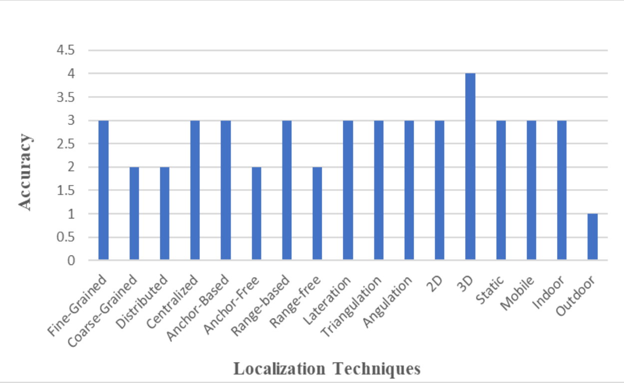

Figure 1: Accuracy Comparison

Figure 1 reveals that 3D shows the highest accuracy among the localization techniques. Fine-grained attains better accuracy than coarse-grained. Distributed techniques attain less accuracy than centralized. Range-based attains better accuracy than range-free. Anchor-based attains better accuracy anchor-free. Indoor achieves better than outdoor.

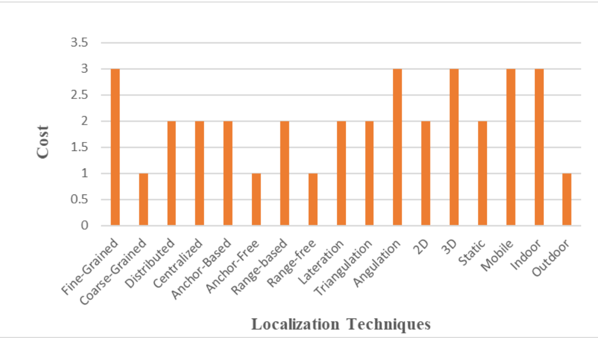

Figure 2: Cost Comparison

Figure 2 shows that fine-grained is more costly than coarse-grained. Anchor-based is more costly than anchor-free. Range-based is more costly than Range-free. 3 D is more costly than 2D. Indoor is more costly than outdoor.

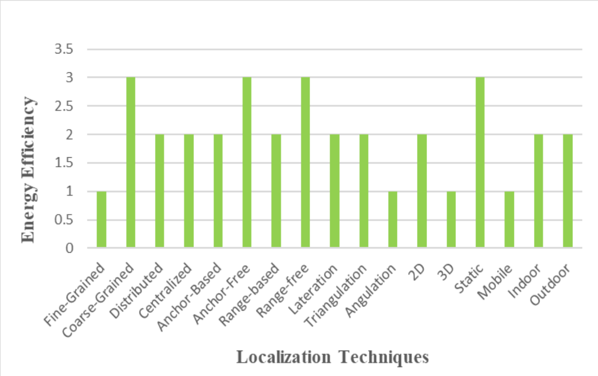

Figure 3: Energy Efficiency Comparison

Figure 3 demonstrates that coarse-grained is more energy efficient than fine-grained. Anchor-based is less energy efficient than anchor-free. Range-based is less energy efficient than range-free. 2 D is more energy efficient than 3D. Static is more energy efficient than mobile.

6. DISCUSSION

In this paper, localisation techniques are classified and analyzed for strengths and shortcomings. To determine their applicability for specific applications, the approaches are assessed for scalability, accuracy, cost, deployment complexity, energy efficiency, and reliability. Based on the findings, there is no general outstanding technique. Accordingly, selecting a specific technique depends on certain requirements and restraints of applications. For example, the range-based techniques are suitable for applications that need high accuracy. On the other, the range-free techniques are suitable for applications that prefer simplicity and low cost. Researchers can use benchmarking analysis to select the most fitting localization techniques for their WSNs.

7. CONCLUSION

This paper provides a inclusive analysis of localization techniques in WSNs, providing valued insights into their classification, pros, cons, and performance metrics. Wireless networks provide real-time monitoring and data collection across multiple applications, making them vital to modern technology. A WSN must detect all relevant events in its environment and provide end customers with relevant and inclusive information to succeed. A well-structured WSN guarantees integral data gathering, assists decision-making, and attains the target aims. The WSN efficacy greatly depends on precise node localization. This leads to ensuring gathered relevant data, supporting decision-making, and generally enhancing network effectiveness. However, there is a need for more research into localization techniques adapting to dynamic environments, such as mobile localization techniques, and those that can handle challenges of indoor and outdoor deployment scenarios. Future work could focus on developing hybrid approaches integrating the advantages of various techniques to achieve optimum performance across varied metrics and application settings. There is a need for case studies and pilot tests to validate the effectiveness of localization techniques in real-world settings. Finally, this paper can be a guide for practitioners and researchers to select the proper localization techniques for their definite applications.

8. REFERENCES

[1] Sneha, V., & Nagarajan, M. (2020). Localization in wireless sensor networks: a review. Cybernetics and

Information Technologies, 20(4), 3-26. https://doi.org/10.2478/cait-2020-0044.

[2] Kuthadi, V. M., Rajalakshmi, S., Baskar, S., Shakeel, P. M., & Ranjan, A. (2021). Optimized energy Management model on data distributing framework of wireless sensor network in IoT system. Wireless Personal Communications, 127(2), 1377–1403. https://doi.org/10.1007/s11277-021-08583-0.

[3] Majid, M., Habib, S., Javed, A. R., Rizwan, M., Srivastava, G., Gadekallu, T. R., & Lin, J. C. W. (2022). Applications of wireless sensor networks and internet of things frameworks in the industry revolution 4.0: A systematic literature review. Sensors, 22(6), 2087. https://doi.org/10.3390/s22062087.

[4] Hoang, T. M., Nam, S. H., & Park, K. R. (2019). Enhanced detection and recognition of road markings based on adaptive region of interest and deep learning. IEEE Access, 7, 109817–109832. https://doi.org/10.1109/ACCESS.2019.2933598

[5] He, Y., Zhang, W., Li, Y., Wang, Y., Wang, Y., & Wang, S. (2021). An approach for surface roughness measurement of helical gears based on image segmentation of region of interest. Measurement, 183, 109905. https://doi.org/10.1016/j.measurement.2021.109905.

[6] Farsi, M., Elhosseini, M. A., Badawy, M., Ali, H. A., & Eldin, H. Z. (2019). Deployment techniques in wireless sensor networks, coverage and connectivity: A survey. IEEE access, 7, 28940-28954. https://doi.org/10.1109/ACCESS.2019.2902072.

[7] Priyadarshi, R., Gupta, B., & Anurag, A. (2020). Deployment techniques in wireless sensor networks: a survey, classification, challenges, and future research issues. The Journal of Supercomputing, 76, 7333-7373. https://doi.org/10.1007/s11227-020-03166-5.

[8] Kanwar, V., & Kumar, A. (2021). Range free localization for three-dimensional wireless sensor networks using multi objective particle swarm optimization. Wireless Personal Communications, 117(2), 901-921. https://doi.org/10.1007/s11277-020-07902-1.

[9] Mohammed, B. H., Sallehudin, H., Mohamed, S. A., Satar, N. S. M., & Hussain, A. H. Bin. (2022). Internet of Things-Building Information Modeling Integration: Attacks, Challenges, and Countermeasures. IEEE Access, 10(July), 74508–74522. https://doi.org/10.1109/ACCESS.2022.3190357.

[10] Zhang, S., & Zhang, H. (2020). A review of wireless sensor networks and its applications. IEEE International Conference on Automation and Logistics, ICAL, August, 386–389. https://doi.org/10.1109/ICAL.2012.6308240.

[11] Gupta, G. P., & Jha, S. (2018). Biogeography-based optimization scheme for solving the coverage and connected node placement problem for wireless sensor networks. Wireless Networks, 25(6), 3167–3177. https://doi.org/10.1007/s11276-018-1709-0.

[12] Baradaran, A. A., & Navi, K. (2020). HQCA-WSN: High-quality clustering algorithm and optimal cluster head selection using fuzzy logic in wireless sensor networks. Fuzzy Sets and Systems, 389, 114–144. https://doi.org/10.1016/j.fss.2019.11.015.

[13] Sharma, D., Mishra, I., & Jain, S. (2017). A detailed classification of routing attacks against RPL in internet of things. International Journal of Advance Research, Ideas and Innovations in Technology, 3(1), 692-703.

[14] Fadele, A. A., Othman, M., Abaker, I., Hashem, T., Yaqoob, I., Imran, M., & Shoaib, M. (2018). A novel countermeasure technique for reactive jamming attack in internet of things. Multimedia Tools and Applications, 23(34), 23–41. https://doi.org/10.1007/s11042-018-6684-z

[15] Yan, X., Cao, J., Sun, L., Zhou, J., Wang, S., & Song, A. (2020). Accurate Analytical-Based Multi-Hop localization with low energy consumption for irregular networks. IEEE Transactions on Vehicular Technology, 69(2), 2021–2033. https://doi.org/10.1109/TVT.2019.2957390.

[16] Mohar, S. S., Goyal, S., & Kaur, R. (2018, December). A survey of localization in wireless sensor network using optimization techniques. In 2018 4th International Conference on Computing Communication and Automation (ICCCA) (pp. 1-6). IEEE. https://doi.org/10.1109/CCAA.2018.8777624.

[17] Bhat, S. J., & Venkata, S. K. (2020). An optimization-based localization with area minimization for heterogeneous wireless sensor networks in anisotropic fields. Computer Networks, 179, 107371. https://doi.org/10.1016/j.comnet.2020.107371.

[18] Bhat, S. J., & Santhosh, K. V. (2021). A Method for Fault Tolerant Localization of Heterogeneous Wireless Sensor Networks. IEEE Access, 9, 37054-37063. https://doi.org/10.1109/ACCESS.2021.3063160

[19] Jawhar, I., Mohamed, N., & Al-Jaroodi, J. (2018). Networking architectures and protocols for smart city systems. Journal of Internet Services and Applications, 9(1), 1-16. https://doi.org/10.1186/s13174-018-0097-0.

[20] Tripathi, A., Gupta, H. P., Dutta, T., Mishra, R., Shukla, K. K., & Jit, S. (2018). Coverage and connectivity in WSNs: A survey, research issues and challenges. IEEE Access, 6, 26971-26992. https://doi.org/10.1109/ACCESS.2018.2833632

[21] Abba, A. M., Sanusi, J., Oshiga, O., & Mikail, S. A. (2023, November). A Review of Localization Techniques in Wireless Sensor Networks. In 2023 2nd International Conference on Multidisciplinary Engineering and Applied Science (ICMEAS) (pp. 1-5). IEEE. https://doi.org/10.1109/ICMEAS58693.2023.10429886.

[22] Sabale, K., & Mini, S. (2021). Localization in wireless sensor networks with mobile anchor node path planning mechanism. Information Sciences, 579, 648-666. https://doi.org/10.1016/j.ins.2021.08.004.

[23] Bhat, S. J., & KV, S. (2022). A localization and deployment model for wireless sensor networks using arithmetic optimization algorithm. Peer-to-Peer Networking and Applications, 15(3), 1473-1485. https://doi.org/10.1007/s12083-022-01302-x.

[24] Patel, N. R., & Kumar, S. (2018, November). Wireless sensor networks' challenges and future prospects. In 2018 International Conference on System Modeling & Advancement in Research Trends (SMART) (pp. 60-65). IEEE. https://doi.org/10.1109/SYSMART.2018.8746937.

[25] Nagaraju, R., Goyal, S. B., Verma, C., Safirescu, C. O., & Mihaltan, T. C. (2022). Secure routing-based energy optimization for IOT application with heterogeneous wireless sensor networks. Energies, 15(13), 4777. https://doi.org/10.3390/en15134777.

[26] Bhat, S. J., & Santhosh, K. V. (2020). Is localization of wireless sensor networks in irregular fields a challenge? Wireless Personal Communications, 114(3), 2017-2042. https://doi.org/10.1007/s11277-020-07460-6.

[27] Niewiadomska-Szynkiewicz, E. (2012). Localization in wireless sensor networks: Classification and evaluation of techniques. International Journal of Applied Mathematics and Computer Science, 22(2), 281-297. https://doi.org/10.2478/v10006-012-0021-x.

[28] Rai, S., & Varma, S. (2017). Localization in wireless sensor networks using rigid graphs: A review. Wireless Personal Communications, 96(3), 4467-4484. https://doi.org/10.1007/s11277-017-4397-7.

[29] Avhankar, M. S., Pawar, J., & Byagar, S. (2022, December). Localization Algorithms in Wireless Sensor Networks: Classification, Case Studies and Evaluation Frameworks. In 2022 Fourth International Conference on Emerging Research in Electronics, Computer Science and Technology (ICERECT) (pp. 01-07). IEEE. https://doi.org/10.1109/ICERECT56837.2022.10059606.

[30] Wang, S., Wang, Y., Li, D., & Zhao, Q. (2023). Distributed relative localization algorithms for multi-robot networks: A survey. Sensors, 23(5), 2399. https://doi.org/10.3390/s23052399.

[31] Paul, A. K., & Sato, T. (2017). Localization in wireless sensor networks: A survey on algorithms, measurement techniques, applications and challenges. Journal of sensor and actuator networks, 6(4), 24. https://doi.org/10.3390/jsan6040024.

[32] Sivasakthiselvan, S., & Nagarajan, V. (2020, July). Localization techniques of wireless sensor networks: A review. In 2020 International Conference on Communication and Signal Processing (ICCSP) (pp. 1643-1648). IEEE. https://doi.org/10.1109/ICCSP48568.2020.9182290.

[33] Luo, Q., Liu, C., Yan, X., Shao, Y., Yang, K., Wang, C., & Zhou, Z. (2022). A distributed localization method for wireless sensor networks based on anchor node optimal selection and particle filter. Sensors, 22(3), 1003. https://doi.org/10.3390/s22031003.

[34] Chowdhury, T. J., Elkin, C., Devabhaktuni, V., Rawat, D. B., & Oluoch, J. (2016). Advances on localization techniques for wireless sensor networks: A survey. Computer Networks, 110, 284-305. https://doi.org/10.1016/j.comnet.2016.10.006.

[35] Cheng, J., Li, Y., & Xu, Q. (2022). An Anchor Node Selection Scheme for Improving RSS-Based Localization in Wireless Sensor Network. Mobile Information Systems, 2022(1), 2611329. https://doi.org/10.1155/2022/2611329.

[36] Ahlqvist, V., Holmberg, P., & Tangerås, T. (2022). A survey comparing centralized and decentralized electricity markets. Energy Strategy Reviews, 40, 100812. https://doi.org/10.1016/j.esr.2022.100812.

[37] Liu, H., Tan, Q., Shi, Y., Yu, B., & Zhang, M. (2024). Enhancing indoor thermal comfort and energy efficiency: A comparative study of RC-PCM Trombe wall performance. Renewable Energy, 227, 120542. https://doi.org/10.1016/j.renene.2024.120542.

[38] Sharma, N., & Gupta, V. (2020). Meta-heuristic based optimization of WSNs Localisation Problem-a Survey. Procedia Computer Science, 173, 36-45. https://doi.org/10.1016/j.procs.2020.06.006.

[39] Akram, J., Munawar, H. S., Kouzani, A. Z., & Mahmud, M. P. (2022). Using adaptive sensors for optimized target coverage in wireless sensor networks. Sensors, 22(3), 1083. https://doi.org/10.3390/s22031083.

[40] Alrajeh, N. A., Bashir, M., & Shams, B. (2013). Localization techniques in wireless sensor networks. International journal of distributed sensor networks, 9(6), 304628. https://doi.org/10.1155/2013/304628.

[41] Savić, T., Vilajosana, X., & Watteyne, T. (2022). Constrained localization: A survey. IEEE Access, 10, 49297-49321. https://doi.org/10.1109/ACCESS.2022.3171859.

[42] Singh, S. P., & Sharma, S. C. (2015). Range free localization techniques in wireless sensor networks: A review. Procedia Computer Science, 57, 7-16. https://doi.org/10.1016/j.procs.2015.07.357.

[43] Nagaraju, S., Gudino, L. J., Tripathi, N., Sreejith, V., & Ramesha, C. K. (2021). Mobility assisted localization for mission critical Wireless Sensor Network applications using hybrid area exploration approach. Journal of King Saud University-Computer and Information Sciences, 33(5), 608-618. https://doi.org/10.1016/j.jksuci.2018.04.008.

[44] Jia, W., Qi, G., Liu, M., & Zhou, J. (2022). A high accuracy localization algorithm with DV-Hop and fruit fly optimization in anisotropic wireless networks. Journal of King Saud University-Computer and Information Sciences, 34(10), 8102-8111. https://doi.org/10.1016/j.jksuci.2022.07.022.

[45] Zafari, F., Gkelias, A., & Leung, K. K. (2019). A survey of indoor localization systems and technologies. IEEE Communications Surveys & Tutorials, 21(3), 2568-2599. https://doi.org/10.1109/COMST.2019.2911558

[46] Singh, P., Mittal, N., & Salgotra, R. (2022). Comparison of range-based versus range-free WSNs localization using adaptive SSA algorithm. Wireless Networks, 28(4), 1625-1647. https://doi.org/10.1007/s11276-022-02908-y.

[47] Isaia, C., & Michaelides, M. P. (2023). A review of wireless positioning techniques and technologies: From smart sensors to 6G. Signals, 4(1), 90-136. https://doi.org/10.3390/signals4010006.

[48] Shen, X., Xu, B., & Shen, H. (2023). Indoor Localization System Based on RSSI-APIT Algorithm. Sensors, 23(24), 9620.

[49] Hadir, A., Kaabouch, N., El Houssaini, M. A., & El Kafi, J. (2023). Range-free localization approaches based on intelligent swarm optimization for internet of things. Information, 14(11), 592. https://doi.org/10.3390/info14110592.

[50] Cao, Y., & Xu, J. (2023). DV-Hop-based localization algorithm using optimum anchor nodes subsets for wireless sensor network. Ad Hoc Networks, 139, 103035. https://doi.org/10.3390/s23249620.

[51] Abdulhussein Abdulzahra, S., & Al-Qurabat, K. M. (2024). Exploring Radio Frequency-Based UAV Localization Techniques: A Comprehensive Review. International Journal of Computing and Digital Systems, 15(1), 1565-1581. http://dx.doi.org/10.12785/ijcds/1501111.

[52] Liu, W., Luo, X., Wei, G., & Liu, H. (2022). Node localization algorithm for wireless sensor networks based on static anchor node location selection strategy. Computer Communications, 192, 289-298. https://doi.org/10.1016/j.comcom.2022.06.010.

[53] Patwari, N., Ash, J. N., Kyperountas, S., Hero, A. O., Moses, R. L., & Correal, N. S. (2005). Locating the nodes: cooperative localization in wireless sensor networks. IEEE Signal processing magazine, 22(4), 54-69. https://doi.org/10.1109/MSP.2005.1458287.

[54] Sharma, G. (2022). Lateration-Specific Localization Algorithm for Wireless Sensor Networks. CVR Journal of Science and Technology, 23(1), 31-36. https://doi.org/10.32377/cvrjst2306.

[55] Wahab, N. H. A., Sunar, N., Ariffin, S. H., Wong, K. Y., & Aun, Y. (2022). Indoor positioning system: A review. International Journal of Advanced Computer Science and Applications, 13(6).

[56] Sesyuk, A., Ioannou, S., & Raspopoulos, M. (2022). A survey of 3D indoor localization systems and technologies. Sensors, 22(23), 9380. https://doi.org/10.3390/s22239380.

[57] Halder, S., & Ghosal, A. (2016). A survey on mobile anchor assisted localization techniques in wireless sensor networks. Wireless Networks, 22(7), 2317-2336. https://doi.org/10.1007/s11276-015-1101-2.

[58] Sachin Gopal, Dr. Binu G. (2015). Review on Different Localization Schemes in Wireless Sensor Networks. International Journal of Engineering Research & Technology (IJERT), Vol. 4 (07).