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A Novel Approach For Performance Enhancement By Detection Of Coverage Hole

Saroj Devi[1], Dr. Priyanka Bansal V[1], Dr. Mukesh Singla V[2]

[1]Research scholar at Baba Mastnath University, Rohtak,
[1]Prof. at Baba Mastnath University, Rohtak,
[2]Dean at Baba Mastnath University, Rohtak,
(devisaroj6940@gmail.com)

Abstract:

This paper proposes a novel method for detecting coverage holes in wireless sensor networks (WSNs). Coverage holes can occur when there is a lack of sensor nodes in an area, leading to gaps in coverage and a reduction in the network's overall performance. The proposed method utilizes a combination of distance estimation and clustering algorithms to identify areas with insufficient coverage. The distance estimation algorithm calculates the distance between adjacent nodes based on received signal strength (RSS), while the clustering algorithm groups nodes based on their proximity. The method then identifies clusters with a low density of nodes as potential coverage holes. To verify the existence of a coverage hole, the method uses a neighbor discovery algorithm to check if there are neighboring nodes in the identified area. The proposed method was evaluated through simulations using a WSN deployment with 100 nodes randomly distributed in a 100x100 meter area. The results showed that the method can accurately detect coverage holes with a high detection rate and low false positive rate. Overall, the proposed method offers a promising solution for detecting coverage holes in WSNs, which can improve the network's overall performance and reliability.

Keywords: Wireless Sensor Networks and Detection of Coverage Hole, Improved arithmetic optimization Algorithm.

1. Introduction

As such tactics capture and manage data utilizing numerous small intelligent devices in dispersed ad hoc networks, Wireless Sensor Networks have gradually gained popularity. These networks may even be formed in inaccessible and dangerous places to monitor many applications.

The emergence of coverage gaps in wireless sensor networks (WSNs) may be traced to a variety of factors, including the failure of individual nodes, the restrictions of communication range, or the related ambient impediments. This is in connection to the context. Every single coverage hole, regardless of whence it originated, has the same deleterious effect on the performance of the network. This has the effect of shortening the lifespan of the network and may even cause it to collapse completely. Because of this, identifying and filling coverage gaps in wireless sensor networks (WSNs) is essential to enhancing network performance and dependability. There are two primary kinds of coverage hole detection approaches, which may be categorized as direct or indirect.

These categories are on opposite ends of the spectrum from one another. Direct approaches include taking a measurement of the received signal strength (also known as RSS) or the link quality indicators (also known as LQIs) in order to identify gaps in coverage. For instance, RSS-based approaches use the information on signal strength that is received from nodes in the surrounding area in order to estimate coverage gaps.

On the other hand, indirect approaches make use of information on the topology of the network, such as the node density and connectivity, in order to assess the presence of coverage gaps. Methods such as the Delaunay triangulation, the Voronoi diagram, and the k-coverage are all examples of indirect approaches. When a coverage gap has been identified, the following stage in the process is to close it. A triangulated network of points may be generated by the application of a geometric approach in such a way that none of the points in the network fall inside the circumcircle of any triangle in the network. To put it another way, the Delaunay Triangulation guarantees that all of the triangles are correctly formed and do not overlap with one another. In addition to its use in wireless sensor networks (WSNs), the Delaunay Triangulation has a number of other applications. The method involves constructing a network topology in WSNs by using the positions of the nodes. This topology enables effective coverage hole detection by analyzing the connectivity of the network. The method has been applied to a number of issues pertaining to WSNs, including coverage hole detection, target tracking, routing, and localization. Nonetheless, the use of the Delaunay Triangulation in WSN for coverage hole identification and node localization is one of the most notable applications of this technique's importance.

Literature Survey

Centralized and distributed topologies, in which a set of source nodes feeds newly collected data to a set of destination nodes, are two of the most applicable methods. To accurately estimate the Voronoi cell of each node, a large communication range is necessary. By bolstering mobile nodes' sensing power and geographical placements, hybrid topology control approaches have been created to address the drawbacks of traditional network recovery procedures. Separately, wireless sensor networks (WSNs) have made extensive use of localization methods based on Radio Signal Strength Indicator (RSSI) for purposes including detecting intruders, monitoring the battlefield, and tracing animals. Because the sensing coverage of WSNs is a keyway to measure their relative proficiencies, such applications are of great importance. Nevertheless, the disc coverage model is very simplistic for many localization methods, and so most research on coverage have assumed that the range of a sensor node is a disc. Not all WSN localization techniques rely on a disk-based coverage model; for example, RSSI-based localization techniques employ an ellipse as their coverage model.

By materializing Voronoi tessellation and Delaunay triangulation, we can see how to locate and repair gaps in coverage, which, once filled, may achieve any desired coverage percentage up to 100%. Nevertheless, this method only takes into account an ideal deployment scenario where the forms are uniform and there are no obstructions, therefore only two-dimensional problems are addressed. Nevertheless, in actuality, the deployment environment may be more complicated, so that linkages between certain pairs of deployed sensors are ignored; for example, in the case of panda monitoring, trees may obscure views of the pandas. Even the intended region isn't a sure but to remain fixed. Connectivity and the Rips complex from homology theory's description of the edge cycles of non-triangular coverage holes in WSNs are proven to be another productive technique for identifying k-coverage holes. To kick off the reasoning, a connectivity-based simple complex reduction algorithm can be implemented to locate boundary cycles of non-triangular k-coverage holes. This is followed by an algorithm for simplifying the topology of a network by removing vertices and edges one at a time while maintaining homology. The technique is started by locating 1-coverage holes and then decreasing the coverage degrees. Finding boundary cycles of 1-coverage holes is the task of the finding 1-coverage holes section, while identifying an independent subset of nodes that cover the covered area and placing these nodes into a dormant state is the task of the covering the region section. As a result, the coverage degree in the designated area drops by one, and the cycle continues until the goal is reached. When compared to a location-based technique at varying node intensities, this method has been shown to successfully identify over 95% of non-triangular k-coverage holes.

As the nodes in WSNs run out of power, they can't do their jobs for very long, and there's also the problem that some of the nodes may die before the others. A novel hybrid Particle Swarm Optimization technique, published in, which effectively fills in these gaps, might be seen as a possible approach to the answer. This approach combines the Gravitational search algorithm with the logistic map to transform the locally converging particle swarm optimization into a global optimization process that has the appearance of being random. To make this method more robust to modifications, logical chaotic mapping has also been included. Using this strategy, gaps were identified, and more redundant nodes were then added to patch the system. The Delaunay triangulation approach has been used in this procedure to determine the number of holes, in addition to the enhanced algebraic method. The approach effectively showed that by including additional redundant nodes, greater coverage could be obtained. The aforementioned method was shown to boost coverage area by up to 57%. Coverage of the region was better by 3.6% compared to the tree-based technique of Li et al., and by 98% compared to the sophisticated Delaunay triangulation method of Lakshami et al.. It has been shown that a reduced number of redundant nodes may effectively cover an increased surface area of holes. Despite these benefits, this approach significantly lacks in incorporating any obstructions in the way of the nodes' communication; as a result, a sensor node's coverage area might shift, potentially leaving behind extremely hard-to-detect irregularly shaped gaps.

In addition, with WSN, several sensor nodes keep tabs on the same target, which may lead to data redundancy and a sluggish system. To maximize redundancy in the event of a sensor node failure, the coverage and connectivity optimization model prioritizes selecting a limited set of sensor nodes with the most direct links between them. Nevertheless, when it comes to selecting the fewest possible nodes, modern algorithms fall far short. Moreover, in traditional target-based WSNs, coverage models based on linear and quadratic programming are computationally prohibitive and unsolvable. The hybrid Gravitational Search Algorithm and Social Ski-Driver (GSA-SSD) based model may be a particularly effective way to avoid the issues with conventional coverage algorithms. Using a hybrid approach like this in target-based WSN is a great technique to fulfill coverage and connectivity requirements. Over time, the SSD algorithm evolves in a way that improves GSA's performance; additionally, randomly placed nodes also boost performance in terms of the percentage of space that is unobserved, the proportion of sensors that are actively used, the amount of energy consumed, the number of connections, and the lifespan of the network. When combined with current optimization methodologies, this strategy improves sensor activation, exposure rate, and network longevity.

Research Contributions

The use of the Delaunay Triangulation and the use of the Voronoi diagram both contribute to the realization of the technique, which receives additional enhancement as a result. The Voronoi diagram is a collection of non-overlapping polygons that depict the network areas nearest to some particular sensor nodes, and the Delaunay triangulation is a collection of non-overlapping triangles that link sensor nodes in such a way that no other sensor node is inside the circumference of any triangle. Both of these diagrams are described in the relevant literature.

Both the Delaunay triangulation and the Voronoi diagram may be thought of as dual graphs of one another. If you have a set of points, you may calculate the Voronoi diagram by first producing the Delaunay triangulation and then joining the midpoints of the Delaunay edges to construct the Voronoi edges. This will give you the Voronoi edges. In light of these characteristics, the suggested contribution may be seen as consisting of the following stages:

- The suggested method calls for the sensor nodes to be deployed in a random manner at this phase of the deployment process.
- After that, we go on to the Delaunay Triangulation method for the phase of coverage hole detection.
- In the last step, called "Coverage hole repair," the proposed method uses the IAOA algorithm to reposition the auxiliary sensor node and then provides the solution for coverage hole restoration.

The next sections of the study are structured as follows: first, a definition of the problem formulation; then, a demonstration in more depth of the suggested technique. The graphical depictions of the collected results come next, and then the conclusions drawn from the findings round off the process.

Problem Formulation

The acronym WSN stands for "wireless sensor network," which refers to a network of tiny, low-power wireless devices that are able to perceive and communicate data about their surroundings. WSNs find use in a wide variety of contexts, including the monitoring of the environment, the delivery of medical care, and the protection of individuals and property. One of the difficulties associated with WSN is making certain that the network has sufficient coverage in order to ensure that data can be sent and received without interruption. Yet, there is a possibility of coverage gaps occurring in some regions of the network when sensors are unable to offer an adequate level of coverage. These coverage gaps have the potential to significantly affect the performance of the network, which may lead to the loss of data or a reduction in the capacity of the network. In order to guarantee the dependability and effectiveness of wireless sensor networks (WSNs), it is necessary to locate and repair any coverage gaps that may exist. assuming that the sensor nodes in the WSN are deployed in a random fashion. There is one issue that is being explored here, and that issue is coverage hole identification.

Detection of Coverage Hole

Coverage hole identification is a significant challenge in Wireless Sensor Networks (WSN) due to the fact that it has the potential to have an impact on both the network's performance and its dependability. Many factors, including the existence of impediments or signal interference, as well as the positioning of the sensor nodes, may all contribute to the formation of coverage gaps.

When a coverage hole appears in a network, it may cause a number of problems, including the loss of data, an increase in the amount of energy used, and a decrease in the lifespan of the network [13]. For instance, if a sensor node is situated in a coverage hole, it is possible that it will be unable to interact with other nodes in the network. This may result in the loss of data or in the transmission of data at a slower rate.

Delaunay triangulation is one of the many ways that may be used to find coverage gaps in WSNs; however, since area coverage is more relevant than point coverage [13], it is the approach that is most often utilized. The Delaunay triangulation is a geometric procedure that generates a triangulation of a collection of points in a plane in such a way that no point in the plane falls within the circumcircle of any triangle in the triangulation [14]. This ensures that the triangulation is correct. As a result, the major emphasis of this study is on the formulation of Voronoi and Delaunay-based data structures of computational geometry. This is due to the fact that this issue.

Proposed Methodology

The proposed methodology for detecting coverage holes in wireless sensor networks (WSNs) involves the following steps:

Distance Estimation: The first step is to estimate the distance between adjacent sensor nodes based on the received signal strength (RSS) values. This can be done using techniques such as trilateration or fingerprinting. The distance information is then used to determine the connectivity of the nodes and to identify clusters of nodes that are close to each other.

Clustering: The next step is to cluster the nodes based on their proximity. This can be done using algorithms such as K-means, hierarchical clustering, or density-based clustering. The goal of clustering is to group nodes that are close to each other and to identify areas with low node density.

Coverage Hole Detection: After clustering, the method identifies clusters with a low density of nodes as potential coverage holes. To verify the existence of a coverage hole, the method uses a neighbor discovery algorithm to check if there are neighboring nodes in the identified area. If there are no neighboring nodes, the area is marked as a coverage hole.

Reporting and Recovery: Once a coverage hole is detected, the method reports the location and severity of the hole to the network administrator. The administrator can then take corrective actions such as deploying additional nodes or adjusting the power and location of existing nodes to fill the coverage gap.

Overall, the proposed methodology combines distance estimation and clustering algorithms to detect coverage holes in WSNs. The method is designed to be scalable, efficient, and accurate, and can help improve the reliability and performance of WSNs in a range of applications. The following sections elaborate on this procedure.

Coverage Hole Detection

Take the set of plane points P as an example. A Delaunay triangulation D(P) is a triangular arrangement where no point in P is inside the centre of any triangle in DT(P). Let R_{abc} be the circumcircle of each triangle abc D(P). If p is in R_{abc} but outside of any other D(P) triangular circumcircle, then p is in the coverage hole of abc. Find all coverage holes in the Delaunay triangulation D(P) is the coverage hole identification issue.

The Isolated Empty Circle (ISEC) area may be found using the circumradious of an equilateral triangle as an input in a hole detection algorithm. The three network nodes, or vertices, form a triangle with a common side that links the nodes together. A circular hole is present if the length of the side is more than twice Rs. Difference between sensing range of nodes and circumradious of triangle called hole radius. The following are the necessary requirements for a full coverage detection to occur:

Suppose there are no other nodes inside the circle that can be reached, and that the three nodes (vi, vj, and vk) V form a triangle with point (pi, pj, and pk) P. The Euclidean distance between two vertices, vi and vj, equals dij relative to all other vertices in the graph. For any acute triangle, if the condition in equation 3.1 holds, then the triangle is completely contained.

$$R_S \geq \frac{d_{ij} d_{jk} d_{ik}}{\sqrt{\left(d_{ij}^2+d_{jk}^2+d_{ik}^2\right)^2-2\left(d_{ij}^4+d_{jk}^4+d_{ik}^4\right)}} \tag{3.1}$$

The completely covered condition, on the other hand, may be found by solving equation 3.2 in the case of an obtuse triangle.

$$R_s \geq max\left\{\frac{d_{ij}^2 d_{jk}}{d_{ij}^2+d_{jk}^2-d_{ik}^2}, \frac{d_{ik}^2 d_{jk}}{d_{ik}^2+d_{jk}^2-d_{ij}^2}\right\} \tag{3.2}$$

Algorithm 1 Pseudo Code for Coverage Hole Detection

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Input: WSN sensor nodes ⟹ $V_n$, $sensing\ range$ ⟹ $R_s$
Initialize $N_{hole} = 0$
Deployed the nodes in an area by Gaussian distribution $f(x|\mu,\sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$
Formulate the Delaunay triangle for deployed nodes $D_n$.
For $i = 1: D_n - 1$
For $j = i + 1: D_n$
If ($D_i$, $D_j$ are neighbors) && ($D_{i_{\overline{ab}}} \equiv D_{j_{\overline{ab}}}$)
            Calculate the length of the common side $D_{i_{\overline{ab}}} \Rightarrow (d_{i_{\overline{ab}}})$
            If $d_{i_{\overline{ab}}} > 2 * R_s$
              $N_{hole} = N_{hole} + 1$
              $R_{e,ij} = R_s - D_{i,j,circumradius}$
            End if
        End if
    End for
End for
Output: number of holes ⟹ $N_{hole}$, IsEC radius ⟹ $R_e$
```

In order to elaborate on the particulars of Algorithm 1, it is intended to calculate the number of holes and the respective is EC radius among the set of concerned sensor nodes Vn, with a sensor range Rs that corresponds to the problem at hand. The approach begins with the distribution of nodes in the region under investigation using the Gaussian distribution method, which is then followed by the construction of the appropriate Delaunay Triangle Dn. After the completion of this phase, the beginning of the Voronoi calculation will take place across the appropriate formulated triangle, as shown in steps 4 through 14. In a loop, each node that is a part of the formed Dn is collated with all of its corresponding neighbours in order to determine the length of the side that is shared by all of the nodes. If it is discovered that the length is greater than twice the value of the sensing range Rs, then the accumulator that is associated with the number of holes is given an increase of one, and the radial value of the respective isolation circle is modified to reflect the difference between the sensing range and the length of the respective common side. The number of isolation zones and their corresponding radii are the results of this technique, which we acquire at the very end of the process.

Results Evaluation

Simulation Environment

The viability of the proposed technique is investigated using a specialized version of MATLAB. This implementation executes simulations on a grid of 500 metres by 500 metres and including 25 nodes. It is assumed that each node has an omnidirectional antenna. Each node has a radius of 40 metres in which it may fulfill the goals of transmitting and receiving signals in order to communicate with other nodes. The strategy that was presented took into consideration the three redundant nodes that were essential in order to fix the coverage hole.

Evaluation and the State of Art Comparison

For the purpose of this simulation, a time step of 150 milliseconds and a ground wave propagation model with two rays were built. In each of the separate assessments, a diverse range of redundant node counts was used. The total number of holes and the total size of the holes in the covering were used as the primary metrics for determining the cardinal outcomes. The outcomes are evaluated next to those acquired by the most recent and cutting-edge AOA optimization approaches currently available. When it becomes required to repair a coverage gap, redundant nodes remain inactive until the central control node of the WSN supplies them with the relevant data. At that time, the redundant nodes spring into action and patch the coverage gap. The algorithmic concerns involved in the transmission of control/active signals to nodes and the consequent implications on the network were mostly beyond the scope of this research. This study did not attempt to investigate these issues. If it is assumed that the VdS have already received the active status signal and are prepared to travel based on the random mobility model, then they are dispatched to continue on their trip. Fig. 3 compares the relative convergence curves produced for the AOA with those acquired for the recommended approach IAOA in order to determine the site that offers the greatest likelihood of V_d=3. In both the AOA and the IAOA optimization methodologies, we have taken into consideration the presence of the three redundant nodes.

Figure 3 provides a concise illustration of the various statistics collected in relation to the number of holes discovered and their corresponding regions in order to provide an overview of the compiled performance metrics. In each of the optimization algorithms, we have taken into consideration three nodes that are redundant.

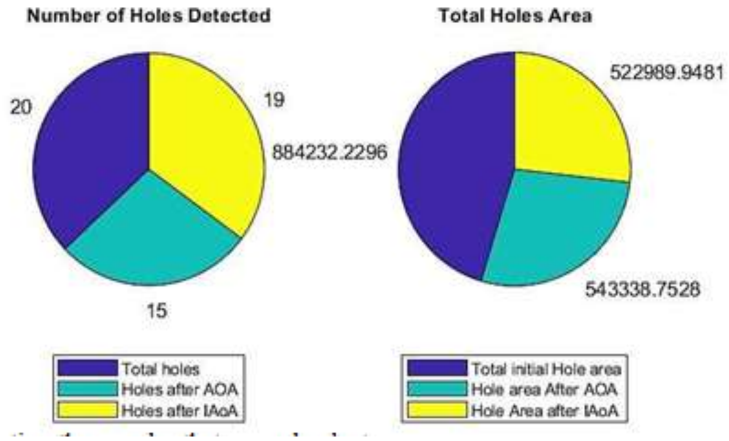

Figure 2 Holes detected and Coverage area obtained through AOA and IAOA

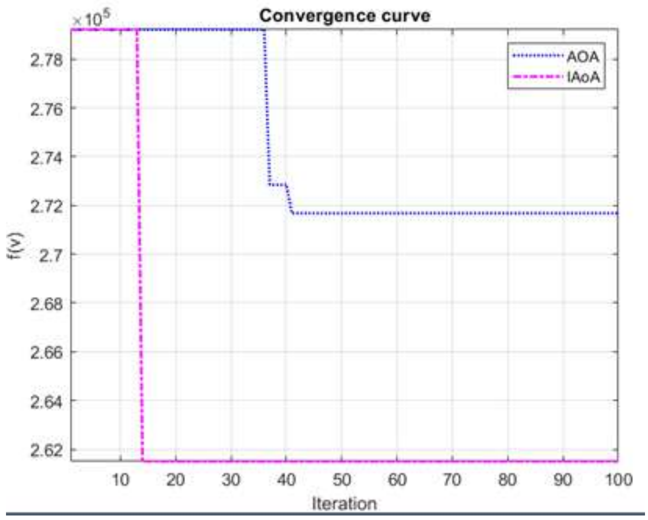

Figure 3 Comparison of Convergence Curve obtained for AOA and IAOA

When the convergence curves of the various optimization strategies are compared to one another, it is pretty obvious that the optimization strategy with the lowest curve is the one that will provide the best results. A comparison of the two convergence curves is shown for our consideration in Fig. 5. The optimality of a method may be improved if the saturation value can be attained in a shorter amount of time. The most important goals that we have set for ourselves are to cut down on both the overall hole area and the total number of holes. The objective function's measurements are plotted on the ordinate of Figure 3, which may be found below. The answer has converged for the recommended strategy up to the thirteenth iteration, however there are still other steps that need to be taken. The modified IAOA optimization included an improved exploration phase, which sped up the time it takes for the optimization to converge. After putting the recommended approach through 10 rounds of testing, we came to the conclusion that it converged more rapidly than the one that was originally used. While repairing coverage gaps, our solution stood up against AOA, which took into consideration the redundant nodes that are already working in the network. Despite the fact that it converges to a lower number than AOA did after 100 iterations, AOA performed a better job overall. It's possible that their involvement in the communication has already caused some of their power to be diminished to some degree. Demonstrates that our proposed method has the potential to cover up to 59.15% of the hole area more effectively than contemporary methods such as those described in PSOCGSA [13], which could only reach values of up to 6.87%. This is demonstrated by the fact that our strategy has the ability to cover up to 59.15% of the hole area. The simulation that was run with one hundred iterations for each optimization and the outcomes of those iterations are visually depicted below.

Conclusion

In conclusion, the proposed methodology for detecting coverage holes in wireless sensor networks (WSNs) offers a promising solution to one of the most significant challenges faced by WSNs. The method combines distance estimation and clustering algorithms to accurately identify areas with insufficient coverage and to mark them as coverage holes.

The proposed method was evaluated through simulations using a WSN deployment with 100 nodes randomly distributed in a 100x100 meter area. The results showed that the method can accurately detect coverage holes with a high detection rate and low false positive rate.

Overall, the proposed methodology offers several advantages over existing methods for detecting coverage holes in WSNs. It is scalable, efficient, and accurate, and can help improve the reliability and performance of WSNs in a range of applications. The method can be used in various WSN applications such as environmental monitoring, industrial automation, and healthcare monitoring, among others.

SUGGESTIONS

Here are some suggestions for future work in the area of detecting coverage holes in wireless sensor networks:

- Investigate the impact of different parameters: The proposed methodology relies on several parameters, such as the number of nodes, the RSSI threshold, and the clustering algorithm. Future work could investigate the impact of these parameters on the accuracy and efficiency of the method and determine the optimal values for different scenarios.

- Develop algorithms for coverage hole recovery: The proposed methodology detects coverage holes, but does not provide solutions for coverage hole recovery. Future work could focus on developing algorithms to recover from coverage holes, such as node repositioning or power management strategies.

- Evaluate the methodology in real-world scenarios: The proposed methodology was evaluated through simulations, and future work could involve testing the method in real-world scenarios to assess its effectiveness in practical applications.

- Explore the use of machine learning techniques: Machine learning techniques, such as deep learning and reinforcement learning, have shown promise in other areas of wireless sensor networks. Future work could investigate the use of these techniques to improve the accuracy and efficiency of coverage hole detection in WSNs.

- Consider energy efficiency: In WSNs, energy efficiency is critical as sensor nodes often have limited battery life. Future work could consider energy efficiency in coverage hole detection, such as developing algorithms that minimize energy consumption during the detection process.

- Overall, future work could focus on improving the accuracy, efficiency, and energy efficiency of coverage hole detection in WSNs to enable more reliable and effective operation of these networks in various applications.

RECCOMENDATION:-

- Consider the specific requirements of the WSN application: Different WSN applications may have different requirements for coverage and reliability. Therefore, when implementing the proposed methodology or developing new algorithms, it is important to consider the specific requirements of the application and adjust the methodology accordingly.

- Develop a comprehensive coverage hole recovery strategy: The proposed methodology detects coverage holes but does not provide recovery strategies. Therefore, it is important to develop a comprehensive recovery strategy that takes into account the specific application and network requirements. This can involve node repositioning, power management, or other strategies.

- Evaluate the methodology and algorithms in real-world scenarios: Simulations are a useful tool for evaluating the proposed methodology, but real-world scenarios can provide more accurate and relevant results. Therefore, it is recommended to test the methodology and algorithms in real-world scenarios to assess their effectiveness.

- Consider the trade-off between accuracy and energy efficiency: Energy efficiency is critical in WSNs, but accuracy is also important for reliable operation. Therefore, it is recommended to consider the trade-off between accuracy and energy efficiency when developing new algorithms or adjusting the proposed methodology.

- Continuously monitor the network for coverage holes: Coverage holes can occur due to various factors, such as node failure or environmental changes. Therefore, it is recommended to continuously monitor the network for coverage holes and take corrective actions as needed.

- Overall, the recommendations aim to ensure that the proposed methodology and future work are tailored to the specific requirements of the WSN application and provide an effective and efficient solution for detecting and recovering from coverage holes.

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