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Optimizing Coverage and Clustering Techniques for Mobile Wireless Sensor Networks

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ABSTRACT: Mobile Wireless Sensor Networks (M-WSNet) present unique challenges due to the dynamic nature of node movements and changing environmental conditions. Efficient coverage and clustering strategies are essential for ensuring reliable data gathering and network longevity in such environments. This paper proposes a review of existing approaches to optimize coverage and clustering techniques in MWSNs. The review begins by outlining the significance of M-WSNet in various application domains and the specific challenges posed by their dynamic nature. The authors highlight the necessity for adaptable strategies that can accommodate node mobility and environmental changes while maintaining robust network performance. In addition to coverage optimization, the review discusses the proposed clustering mechanism designed to enhance energy efficiency and reduce communication overhead in M-WSNet. By organizing sensor nodes into clusters based on proximity and energy levels, the clustering algorithm facilitates efficient data aggregation and dissemination while preserving network connectivity. The literature extensively explored sensor coverage and connectivity issues for multiple kinds of WSNs, and multiple remedies with varying capabilities and limits were developed. This work aims to present an in-depth categorization of the numerous strategies and procedures used in M-WSNet to improve coverage after inaugural deployment and to sustain coverage after node loss.

KEYWORDS: Mobile Wireless Sensor Network, Coverage, Clustering

I. INTRODUCTION

Mobile Wireless Sensor Networks (MWSNs) are a critical component of modern-day applications, ranging from environmental monitoring to surveillance and healthcare. Ensuring optimal coverage and efficient clustering of sensor nodes in such networks is imperative for maintaining connectivity, prolonging network lifetime, and maximizing data accuracy. The paper under review addresses these challenges through the introduction of novel techniques for coverage optimization and clustering in MWSNs [1-4].

In stationary wireless sensor networks (S-WSN), all installed sensors are static, but sensors in (M-WSNet) are fitted with locomotive systems, allowing them to move after original deployment. Figure 1 depicts the MWSN's design. Mobility is another issue that influences coverage in WSN. Mobility describes nodes' capacity to move position after primary deployment. Inadvertent mobility can result in coverage gaps. Intentional mobility (active movement) can be used to improve coverage, connection, and network longevity.

Everywhere, at any time, the nodes can relocate. The MWSN's dynamic topology is mirrored in the selection of further differentiating features such as connectivity, MAC level protocols, and physical properties. In a static WSN, a network that is interconnected can dissolve into an assortment of unconnected subnetworks owing to hardware malfunction or energy depletion. With MWSN, nodes can be used to reorganize the network. Mobile sensors can be relocated after initial deployment to cover energy gaps in the network and reach the required density [9-11]. You can save energy by speaking while mobile. The channel capability of MWSN exceeds that of static WSN. MWSN achieves integrity of data by minimizing the number of hops, hence decreasing the risk of error.

One of the most significant issues with WSN is coverage. Coverage corresponds with how well each location in the area of interest is monitored by the deployed sensor nodes, and may thus be viewed as a Quality of Service (QoS).

Sensors can be planted at predefined locations to provide coverage; yet, in many applications, the environment is distant and dangerous, thus sensors are set up at random. In the latter scenario, coverage is not constantly assured. Another reason of coverage problems is sensor node breakdown, which can be caused by battery exhaustion or a hardware issue [12]. We feel that the intricate nature and range of coverage kinds and methodologies in WSN require improved, explicit classification and analysis. As a result, in this work, we strive to offer a comprehensive categorization of current coverage kinds. The survey discusses strategies for improving coverage after initial installation and preserving coverage after node failures.

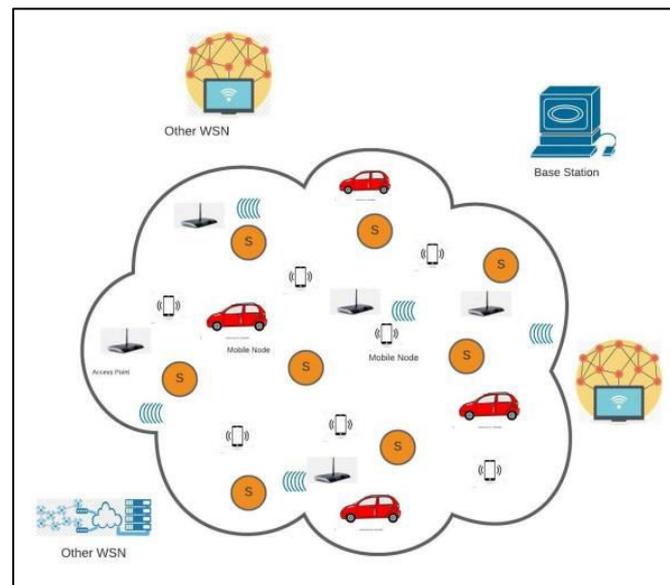


Fig 1: Mobile Wireless Sensor Network [18]

II. RELATED WORK

The Coverage problem in both S-WSN, and M-WSNet is discussed in [16]. Routing is a critical issue in the MWSN because of its highly volatile nature and the constant changes in network design and networking equipment caused by mobile nodes or connectivity failures [17]. The capacity of mobile sensor nodes to store and distribute power is limited. Because of the dynamic nature of the network configuration, some nodes will run out of energy and quit the network, separating it. Many academics have developed routing protocols based on various design difficulties and requirements. MWSN routing protocols can be classified according to their network design, information status, movement, and power-saving measures [18].

They are further classified according to network topology as Direct Communication Routing, Flat-based Routing, and Hierarchical Routing. A sensor node employs direct communication routing to provide data directly to the sink. When the network region is large, the sensor node's power quickly depletes, and the frequency of collisions increases. Direct communication routing is thus rarely employed in MWSNs. The nodes in the flat-based routing system have identical capabilities [16]. Hierarchical protocols automatically group network nodes into smaller divisions known as clusters, which are then joined into larger divisions known as super clusters, and so on. The cluster heads aggregate the data, reducing the volume of data and conserving energy [17]. Cluster leaders are in charge of maintaining authority within their clusters [18].

The literature study in [22] approaches the coverage issue from an alternate perspective. It models dynamic coverage under a variety of presumptions, including connection and collection aversion. Mobile sensors move continuously to achieve evolving coverage, alternating among covered and uncovered points.

III. ADAPTIVE CLUSTERING FOR MOBILITY SCHEDULING

Authors presented a self-organizing and adaptive Dynamic Clustering (DCMDC) approach for managing topology updates and maintaining routes for communication in mobile WSNs. To reduce mobility-triggered signalling cost, we designed and implemented a self-organizing protocol that separates the network into Service Zones (SZs). The network is dynamically clustered into SZs using the convex hull technique. Arranging the network in SZs has numerous benefits. Localizing mobility management traffic saves signalling overhead and improves bandwidth usage. Research consistently shows that reducing congestion leads to fewer queue waits. Network clustering is a proven technique for scalability and load balancing. Classifying nodes into fewer logical groups reduces buffer overflows and energy depletion. Ensuring continuous connectivity with the MDC within the communication range of sensor nodes improves the availability of the system [19].

In [20], the authors presented a self-organization strategy for mobile devices in cluster-based ad-hoc networks. The method is accomplished using a multi-role agent approach. Agents can be assigned as leaders, gateways, or members based on their energy level and surrounding nodes.

Once the network is deployed, roles are assigned. When the leader agent's remaining energy hits a particular threshold, it limits its transmission range to 50%. If it reaches a lower threshold, the leader election mechanism is initiated. Still, the technique builds too many network leaders, resulting in bandwidth waste and high collision rates. In addition, the sensor node weight function takes into account simply the remaining battery and the number of neighbors. It does not take into account node position, mobility speed, or direction.

IV. DEPLOYMENT OF MOBILE NET WITH COMPLETE COVERAGE

The (M-WSNs) are a type of WSN that allows all sensor nodes to move. Sensor mobility can improve data gathering, network coverage, and network longevity. Proposed strategies for improving complete coverage in M-WSNet can be classified corresponding on their objectives and methodology (Figure 2). The primary goal of full coverage is to keep track of all points in the area. Mobile sensor nodes can be utilized for various purposes. a). Mobile nodes may be required in monitoring events contexts (b). They can be utilized for dynamical distribution (c). They can improve coverage, communication, and network longevity.

Dynamic deployment (or self-deployment) improves network coverage by moving sensor nodes following a random first deployment. Mobility is only employed to create a new fixed arrangement with better coverage. Dynamic deployment approaches can be characterized as centralized or dispersed. In centralized approaches, the sink node runs the deployment algorithm and delivers instructions to sensors. These techniques save energy on sensor nodes, but need a powerful sink node, which may not be accessible in certain scenarios (e.g., disaster zones or battlefields). Additionally, they have one point of breakdown. Distributed approaches require each sensor node to establish its new location, resulting in increased energy consumption. Figure 3 describes different types of coverage protocols in M-WSNet.

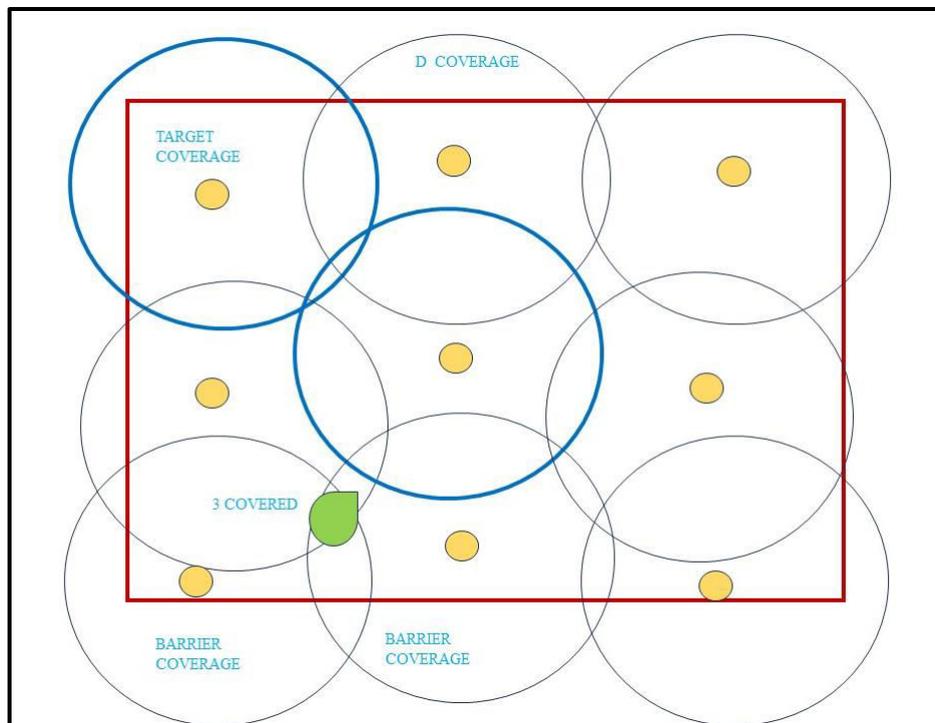


Figure 2: Coverage in M-WSNet

V. VIRTUAL FORCE BASED COVERAGE

Virtual forces have been employed for dynamic deployment and functional augmentation. These methods mimic the behavior of electro-magnetic atoms. Every sensor node works as a source of force, which may be enticing. According to the distance between that sensor and the others, it can be attractive or repellent. Other items in the surroundings, such as obstructions, can also exert force. Authors in [21] propose a centralized VF-dynamic deployment mechanism. Virtual forces determine new best placements for all sensors, after which nodes relocate to conserve energy. The approach requires minimal processing time as all computations are carried out on a centralized server. The method uses a cluster design; hence energy usage is not shared among nodes. In addition, the approach presumes that global knowledge about other nodes is accessible. VOR or Minimax. The VECTOR-based algorithm (VEC) is built on virtual forces. The VORonoi-based algorithm guides sensor nodes to sparsely covered areas. Lastly, Minimax employs Voronoi diagrams. While both VOR and Minimax provide equal coverage, Minimax uses less energy and transmits fewer signals. All three methods use virtual motion to reduce energy use. Still, it has considerable overhead and cannot support partitions in the network [23]. The authors of [22] provide a protocol for improving coverage in H-WSN. As described in [23], static sensors assess coverage holes and give prices (bids) for them. Mobile sensors select the hole with the highest bid for cover. The protocol limits the longest distance between the mobile sensor and the destination site to avoid introducing additional coverage gaps. The efficacy of the procedure varies with the number of mobile devices. The (DOC) algorithm is another dynamic deployment method [24]. The method leverages virtual forces to improve coverage and connectivity. Sensor nodes move based on their distance and angle from neighboring nodes. The efficacy of the algorithm is explored with leads to indicating quick optimization for arbitrarily dispersed sensors that require little time for computation.

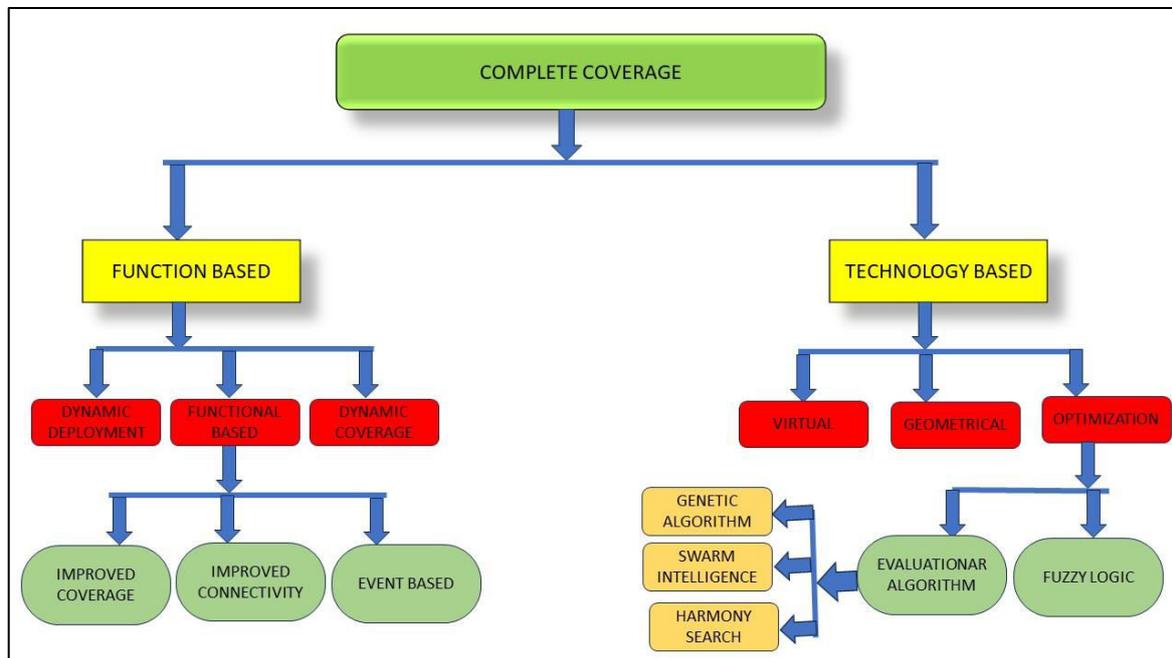


Figure 3: Various Types of M-WSNet. Coverage

VI. GEOMETRY BASED COVERAGE

Computational geometry uses Voronoi diagrams or Delaunay triangulations to represent deployment problems. Voronoi diagrams split a region into multiple polygons based on the sensor's vertical bisector and surrounding points. To improve coverage, sensors move towards uncovered vertices. Delaunay triangulation involves triangulating an area so that no point in any triangle falls within the enclosed circle of another triangle [25]. A distributed deployment technique for mobile sensors is described in [26]. The program generates a hexagonal tiling with each hexagon tile size set to the sensing range of a node. The algorithm is built on the interleaving of four operations: snap, push, pull, and merge. The snap activity begins by selecting one of the nodes as the starting sensor. The push activity moves sensors from high-density tiles to lower-density ones, whereas the pull activity attempts to fill any coverage gaps that may arise. subsequently the merge activity combines any tiling sections that come in radio vicinity when several sensors operate as starts.

In [27], the researchers present a general structure for optimized mobile sensor redeploy in H-WSNs to improve starting coverage. The framework defines coverage as a problem of optimization with three conditions. The initial goal is to reduce the total number of gaps between grids. The second goal is to ensure uniform dispersion of deployed sensors while meeting the first condition. The third goal is to reduce the overall movement cost. The framework splits the deployment area into square-shaped grids and determines the number of sensors for each. The mobile sensors' mobility capabilities are then modelled using a bipartite graph. A bipartite graph is used to create a new network. Optimal fitting of the new network leads to the optimal movement plan for the three-step optimization problem. The algorithm can also handle installations with a variety of sensors and grid coverage specifications. Simulation findings indicate that the structure has the lowest mobility costs.

VII. OPTIMIZATION BASED COVERAGE

Dynamic deployment uses several optimization approaches, including fuzzy logic, particle swarm, ant colony, and harmony search.

Fuzzy-based Optimization

The study in [28] addresses the application of fuzzy logic systems to improve coverage. The system calculates the sensor's moving range based on its neighbours and their average range. The work in [29] proposes a fuzzy-based

priority coverage algorithm (FBPC) for enhancing coverage in M-WSN. Nodes are moved based on their number of neighbours and separation from borders and barriers. The technique uses both fuzzy inference engines and virtual forces. However, the algorithm has a rather high average movement distance.

VIII. EVOLUTIONARY COMPUTATION ALGORITHMS

Swarm Intelligence

Swarm intelligence (SI) is a type of algorithm that relies on insect self-organization and distribution of Labor. Swarm intelligence technologies encompass Particle Swarm Optimization (PSO), Ant Colony (AC), Artificial Honey Bee Colony (ABC), bird flocks, immune system, and others. Several kinds of literature surveys have used PSO to improve coverage.

PSO algorithms attempt to mimic the social behaviour of birds flocking. [30] proposes a virtual force and PSO-based algorithm (VFCPSO) for improving coverage in H-WSN. The method provides improved coverage with substantially less computational effort. Broadcasting beginning and final positions consumes more energy, and requires methods for localization and collision avoidance. The VFCPSO is quite complex and should be applied centrally. A particle swarm deployment algorithm for H-WSN is described in [31]. The DPSOSA method is developed for target tracking applications that require accurate identification. The authors suggest employing simulations of annealing to overcome the local minimum problem in PSO. Additionally, the program takes transmission energy into account.

Artificial bee colony

Dervis Karaboga invented the Artificial Bee Colony (ABC) algorithm, which a population-based discovery method that mimics the habits of honeybees' colonies. A dynamic deployment methodology for H-WSN based on ABC was proposed in [32]. The program randomly installs static nodes and employs the ABC algorithm in establishing the locations of mobile nodes. Experimental findings Show that the algorithm surpasses PSO. Typically, ABC is more appropriate for Dynamic surroundings.

Harmony Search

The Harmony Search (HS) algorithm [33] is an optimization tool influenced by musicians' experiences with jazz improvisation. In recent years, HS has been utilized to alter the sensing radius of static nodes, improving coverage, route planning, and node localization. In [34], an HS-based approach for visual sensor networks is presented. The program optimizes energy usage by reducing sensor rotations and achieving k-coverage for each target. Simulation findings reveal that HS outperforms PSO in terms of speed and convergence. Using better harmony search, the work takes into account both network longevity and coverage. Mobile nodes are regularly relocated from high-energy to low-energy areas to improve network lifespan.

IX. DYNAMIC COVERAGE

Sensors may cover previously hidden areas later on as they travel. Moving sensors can identify intruders that would not be spotted in a fixed sensor network as the area covered expands over time. Subsequently, improved coverage comes with a drawback: a site is only partially covered, and the area is rotated between covered and uncovered. We analyze area coverage at certain times, intervals, and lengths. In [34], the dynamic features of network coverage are investigated. The authors demonstrate how a random mobility model improves coverage over time intervals. This form of coverage is better suited to applications that don't need continuous coverage of every location at specific time points.

In [16], the authors look at how node mobility affects coverage and energy usage in WSNs with different sensing radii. The authors demonstrate how random walk mobility can improve coverage. Additionally, they discuss the relationship between coverage and sensing range. Lastly, they investigate k-coverage over a certain time interval and identify the coverage enhancement caused by mobility.

Authors [3] provide an overall model of a dynamic sensor network with heterogeneous sensors. The authors investigate how sensor mobility can reduce the number of sensors installed. Dynamic coverage involves identifying best pathways for mobile sensors while keeping a connection. Sensor mobility is investigated from an alternative angle in [35]. In HWSN, mobility is employed to dynamically fill coverage gaps left by static sensors. A mobility model has been suggested that leads mobile sensors to optimize the coverage duration of locations that static sensors have not covered. Authors in [36] discusses how mobile sensors might improve static sensor coverage. A distributed-collaborative path

planning paradigm that works for both H-WSN and M-WSN is proposed. Authors in [37] proposes control regulations to meet tracking needs for disaster assistance, rescue operations, and surveillance activities.

X. PARTIAL COVERAGE

Partial coverage ensures a particular level of coverage based on the application needs.

D-Trap Coverage

D-trap coverage, a partial coverage, ensures that moving objects are recognized within a defined dispersion [38]. As a result, it lends itself better to tracking applications. D-trap coverage ensures that the maximum Sensing Void Distance (trap) equals a constant value (D). Yet, the coverage gained in this work may not even be partial. The work in [38] provides a prediction of the essential density required to accomplish a specific sensing void distance. Additionally, a polynomial time approach for determining the level of D-trap coverage of a distributed sensor network is described.

Barrier Coverage

D-trap is appropriate for tracking applications; however, barrier coverage is more suited for identifying breaches and boundary monitoring. This type requires sensors to track a belt region. A belt region can be classed either as open or closed. A belt zone is often developed from left to right, with the intruder moving from top to bottom of the belt. There are two types of models: worst- and best-case coverage and exposure-based algorithms. The maximal breach path (MBP) is the worst-case coverage when any location along the breach path is the furthest distant from the distributed nodes. The maximal support path (MSP), alternatively, shows the best-case coverage by minimizing the distance between the penetration path and the deployed nodes. The suggested approach uses Voronoi diagrams to discover the MBP and the Delaunay triangulation diagram for the MSP.

Sweep Coverage

Sweep coverage is another sort of partial coverage in which a group of sites (sites of Interest (POI)) is tracked on a periodic basis rather than continually [39]. Typically, every POI needs to be checked once per specific period known as the sweep period. POI might have comparable or differing sweep times.

Mobile sensors can provide effective sweep coverage. Due to the constraints of mobile sensor node speed and sweep period time, more than one sensor node is typically necessary to accomplish sweep coverage. A scheduling technique is required to allocate sensor nodes to certain POIs while adhering to time constraints.

In [40], the authors look at sweep coverage for covering a group of line segments on a plane and show that the task is NP-hard. The provided technique, line sweep coverage, determines a tour of a weighted network from a given collection of line segments to determine the number of mobile sensor nodes and their motion pathways, addressing the line sweep coverage issue.

Focused Coverage

In certain fields, like pollution monitoring, it is important to prioritize coverage around a specific occurrence over more distant areas. This form of coverage is known as focused coverage (F-Coverage) [41]. The level of focused coverage is determined by a coverage radius, which is the maximum hole-free disc centered at the point of interest (POI). The authors provide two localized sensor self-deployment algorithms: Greedy Advance (GA) and Greedy-Rotation-Greedy (GRG). Both techniques employ an equilateral triangle tessellation (TT) structure to optimize the coverage area of the deployed nodes while ensuring communication between them.

The methods resist node failure; however, GRG does not guarantee the maximum coverage radius. As a result, an optimized variant of GRG (OGRG) has been suggested to ensure maximum coverage radius.

Target Coverage

Target coverage necessitates ongoing surveillance of a set of stationary targets at known places. A number of studies have looked into the topic of consistent coverage in mobile node-based search and tracking systems. This problem is distinct from its predecessor as the target locations are unclear and movable nodes are employed instead of static ones. To address this issue, the control algorithm must guarantee that the time spent by nodes viewing a neighborhood corresponds to the chance of locating a target in this neighborhood. The authors use mobility to improve target detection. The authors address difficulties such as scheduling mobile node motion to reduce detecting latency. Cooperation between mobile and static sensors maximizes benefit while minimizing overhead. The technique is based

on a clustered H-WSN, with sensors regularly reporting their energy levels to the cluster leader. The cluster head determines whether or not the mobile sensor node has sufficient energy to move. Each mobile node has a movement schedule, which consists of a list of moves. Simulation results indicate that a modest number of mobile sensors can considerably increase system detection accuracy. Considering certain detection latency constraints, the method can attain near-optimal efficiency [42].

XI. CONCLUSION

Overall, the review acknowledges the significance of the contributions made by the proposed coverage and clustering techniques in addressing the unique challenges of MWSNet. The comprehensive evaluation through simulations provides valuable insights into the performance improvements achieved by the proposed algorithms. However, the review also suggests avenues for future research, such as scalability considerations and real-world deployment challenges, to further validate and refine the proposed techniques. In conclusion, the paper offers valuable insights into the optimization of coverage and clustering techniques in MWSNet, laying the foundation for enhanced network performance and reliability in dynamic environments.

WSN is currently used in a wide range of applications, including tracking, safety, and monitoring. Depending on the application's requirements, nodes are usually deployed indeterminately or haphazardly. This study compares various deployment patterns recommended for deterministic deployment. Additionally, recent ways to improve coverage by utilizing node mobility are discussed. WSN coverage is influenced by multiple hypotheses, including sensing models and mobility models and their effect on coverage.

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