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Research Article

Survey on Coverage Hole Optimization in WSN

R.Rajesh[1], Dr. V. Tamizhazhagan[2]

[1]Research Scholar, Department of Information Technology, Annamalai University, Chidambaram, Tamil Nadu- 608002, India ,mtechrajeshr@gmail.com
[2]Assistant Professor, Department of Information Technology, Annamalai University, Chidambaram, Tamil Nadu- 608002, India ,rvtamizh@gmail.com

Abstract— The Wireless Sensor Network (WSN) plays a significant function in today's environment. In general, WSN is widely used in IoT automation. The WSN's sensors will communicate with one another to share the information they've gathered. One of the most common challenges in Wireless Sensor Networks is the issue of coverage. A number of algorithms have been developed to address the coverage issue. We look at a range of coverage maximisation tactics in this survey. Coverage maximisation strategies are divided into groups based on their effectiveness. The merits and downsides of the algorithms are assessed in light of the surrounding circumstances.

Keywords— Coverage, Coverage maximization, algorithms, WSN

INTRODUCTION

WSNs are comprised of a large series of tiny nodes, ranging from a few to hundreds in number. These nodes are known as sensor nodes since they are battery-powered and also have the capacity to discern, process data, and communicate. WSNs, to put it another way, are composed of individual embedded devices that can interact with their surroundings through sensors, process data, and communicate that information with their neighbours. As a result, wireless sensor networking is a low-cost, viable technology with a variety of applications in the defense, healthcare, the environmental, the home, and business, among other sectors. Wireless sensor networks are now conceivable thanks to significant advancements in wireless transmission and incorporated micro-sensing MEMS technology. A huge number of low-cost wireless nodes, each capable of collecting, storing, and analysing environmental information as well as connecting with other nodes, may be present in such environments. Sensors were formerly connected through wire connections. To encourage inter-sensor communication, this ecosystem now contains ground-breaking ad hoc networking technology[1]. The fundamental properties of WSN sensor nodes, such as power consumption, offer a variety of issues for researchers because they are prone to failure owing to energy depletion. Furthermore, due to a variety of factors such as the huge number of sensor nodes, the distribution of nodes in remote regions, the desert, or dangerous conditions, it is not possible to recharge or change the batteries of sensor nodes. WSNs focus on power conversion to increase the network's lifespan, whereas traditional networks strive to enhance metrics like delay and throughput. In WSNs, coverage and connectivity are two major issues that affect service quality. Coverage can be thought of as a measure of service quality in sensor networks [2]. As a result, coverage and energy usage are used to assess network quality. Device calibration, environmental monitoring, and exposure are all dealt with by the service quality sensing component of the quality of service model. Exposure, which is a measurement of a region's coverage, is used to determine the ability to recognise a moving target. Due to limited energy supplies, the dynamic nature of topology, and other network components such as the number of sensors installed, method of implementation, information exchange and sensing ranges associated with sensor network, efficient communication link agreement, sensor node energy usage, and so on, WSNs face a variety of challenges.

PAPER MANAGEMENT

The remainder of the paper is organised as follows: The components of a sensor node in a WSN are covered in Section I, while coverage is defined and classified in Section II. The answer to the coverage problem, as well as various algorithms, are found in Section IV of Section III, Classification of Coverage Problem. Part V contains the conclusion, while the last portion has the references.

1.COMPONENTS OF WSN SENSOR NODES

A wireless sensor network (WSN) is a collection of sensors that can communicate with one another wirelessly. Sensing, communication, computing, and storage containers are the main components of a sensor node. The elements of a sensor network in a WSN are shown in Figure 1.

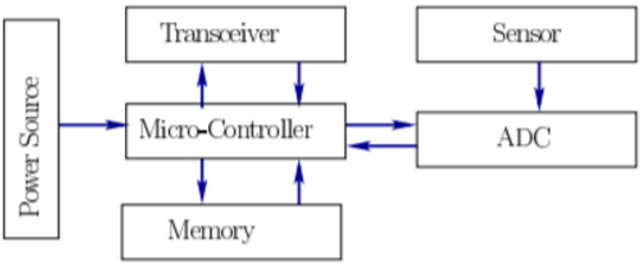


Figure 1.Components of sensor node in WSN

1.1. Sensing Unit

A sensing device that communicates with the physical world makes up a sensor node in a WSN. The two types of sensor network in WSNs are active and passive sensor nodes, which operate differently. The signal strength given by the sensor network and reflected by the target is measured by an active sensor network, which also functions as a monitoring device. To create signals, the sensor module requires an extra power source. The signal power emitted by the physical surroundings is measured using a passive sensor. The passive sensor doesn't really require an external source to generate signals, unlike active sensor nodes. As a result, passive sensor networks use less electricity than active sensor network. The operation of passive and active sensor nodes is depicted in Figure 1. Sensor node signals can be classed as digital or analogue. Binary and continous signals are produced by analogue and digital sensor nodes, respectively.

1.2.Communication Unit.

A sensor node's communication unit is in charge of transmitting and receiving data and control packets. In WSNs, either one 2 different interaction between two sensor network is referred to as either one two-way communication. Multi-hop communication, as according WSN literature [4, can dramatically cut energy consumption in large-scale WSNs.

1.3.Computing Unit

In a sensor node, a processing unit connects to the elements and runs the software. WSN sensor nodes make use of microcomputers, embedded systems, high digital signal, communication processors, and software electronic components for certain functions.

1.4. Storage Unit

Sensor nodes presently have a small, low-cost storage unit. The sensory data and command sets are stored in this storage unit. Random access memory, read-only memory, static random-access memory, and non-volatile memory are the most common forms.

2. COVERAGE AND CLASSIFICATION OF COVERAGE

Coverage

A sensor network's ability to stay connected is crucial. Connectivity refers to the ability of the sensor network to connect with the data sink. If there is no available path from a sensor node to the data sink, the data collected by that node cannot be processed. Each node has a transmission distance that specifies how far it may receive data from other nodes. The sensing range, on the other hand, indicates the area that a node can monitor. Despite the fact that the two ranges are often the similar, they are frequently separate.

2.1. Area Coverage

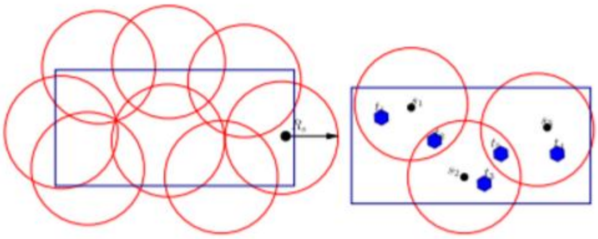
The FoI is monitored by a collection of deployed nodes in WSNs using area coverage, also referred as blanket coverage. Part (a) of Fig. 4 provides an illustration of a randomly deployed WSN monitoring a specific FoI, with circles representing the sensor nodes' detecting range.

2.2. Coverage of the Target

The FoI's assigned targets are tracked via target coverage, also called as point coverage. Figure 2 (b) shows a target coverage situation with three sensor nodes monitoring the FoI's five targets. Targets t1, t3, and t4 are all covered by a single sensor node. At the same time, two devices cover the additional targets, t2 and t5. Target coverage conserves energy because it only checks the supplied location of targets in the FoI.

2.3. Barrier Coverage

Barrier coverage's main purpose is to construct a barrier that can detect incursions. Sensor nodes will be able to identify any intrusions that occur along the barrier. Barrier coverage is divided into two categories based on the accuracy with which events on the FoI's boundary are detected: poor barrier coverage and good barrier coverage. A weak barrier covering has certain uncovered patches or gaps. It just ensures that targets travelling in the same direction are tracked. Certain pathways, on the other hand, may be complicated and thus unidentifiable by any sensor [5]. Intruders must be noticed or detected by the sensor nodes because of the high barrier coverage, as opposed to the inadequate barrier coverage.



(a) (b)

Figure 2- Area Coverage(a) and Target Coverage(b)

3.COVERAGE PROBLEM CLASSIFICATION

3.1.Network Configuration

3.1.1 Network Coverage Determination

These networks are built around preset criteria, such as the network's structure and location of sensor nodes [5]. Sensor nodes are distributed in a deterministic way in this sort of coverage; however, in many circumstances, this is not practical. It's far easier to install sensor nodes in a coverage pattern than it is to cover an area randomly. Determined Network Coverage [6] can be used to solve the coverage problem in an art museum. Computational geometry is concerned with the research of art gallery problems. The chamber is represented by points in the room in this issue, and the guards are illustrated by polygons. The purpose of this challenge is for at least one of the guards to be able to keep an eye on every portion of this room (sensors). Because all of the guards' positions are pre-determined in order to achieve the aim, it is covered.

3.1.2 Coverage at Random

Random network coverage is the total opposite of defined network coverage in that no pre-defined information about sensor positions or network topology is available. The system's topology and location change throughout time. A combat target, for example, can vary its location in response to changes in time and topology. The geometric technique is extensively used for random deployment since it studies the issue of planar coverage [7]. Because nodes in random coverage are considered static, they are put close together to give the necessary coverage; however, in the context of mobile nodes, the movement attribute is used to reposition the best site. As a result, random coverage's goal is to maintain coverage while using as little energy as feasible [8].

4. SOLUTIONS FOR COVERAGE

This section discusses the many coverage options available for obtaining the most effective coverage. Depending on the types of coverage and other considerations, distinct types of coverage strategies and Coverage-aware Deploying Protocols are as follows.

4.1. Area Coverage

Area coverage ensures that the entire area is covered, as well as each individual point inside it. Based on the various requirements for area coverage, the current coverage algorithms can be divided into three categories: 1-coverage algorithms, k-coverage algorithms, and linked coverage algorithms are all examples of coverage algorithms.

4.1.1. Algorithms for Coverage

Several effective area coverage mechanisms are presented in this section. PEAS was a distributed control algorithm based on link density detection, as described in reference [7]. Nodes in PEAS worked in a circular mechanism. Nodes went through two stages in each round: an environment monitoring stage and an adapting stage. The sensor nodes were first put to sleep, and then after a random time interval, they were reawakened. If there had been any survival nodes in within sensor range, the active nodes will recognize them. If this is the case, the node will enter sleep mode; if this is not the case, the node will enter working mode. To ensure that the quality of coverage in wireless sensor networks, PEAS can change the detection range and wake-up intervals. Although PEAS does not require precise geographic information for nodes and the algorithm's cost was not prohibitive, PEAS cannot ensure that the region will be entirely covered.

A distributed node scheduler system was provided in reference [8], which can execute on each sensor node. According to the relationship between the placements of different nodes, the algorithm can examine the potential of one node being redundant. When a node is redundant, it goes to sleep. The method only considered neighbour nodes in its sensing range when judging redundant nodes, however there are other duplicate nodes in active nodes, therefore the mechanism's performance has to be improved.

Given that the mechanism proposed in [8] necessitates knowing the precise position information of nodes, reference [9] suggested three node scheduling algorithms: node scheduling algorithm depending on the number of neighbours, scheduling algorithm based on nearest neighbour, and scheduling algorithm based on probability.

4.1.2. Algorithms for k-Coverage

Coverage algorithms cannot meet the needs of diverse applications in some major environmental monitoring application systems [10], such as fire, gas leakage, explosion, and other monitoring systems. As a result, some studies have begun to look into the k-coverage problem.

The reference [11, 12] proposed a centralised k-decision procedure that simply requires determining whether arbitrary nodes in the perimeter of the sensing disc can be covered by other k nodes and then determining if the entire region is kcovered. The method, however, is a centralised algorithm with an excessively high level of complexity. Sink must conduct too many calculations in large-scale WSN applications, resulting in poor algorithm performance. The mechanism described in reference [13] is a k-coverage configuration protocol that ensures that if any point inside the intersection area of the sensing disc can be k-covered, the entire region can be k-covered as well. However, the mechanism did not take into account the network's contribution value when a node went from sleep to active, resulting in low network coverage efficiency and a higher degree of node redundancy.

4.1.3. Algorithms for Connected-Based Coverage

Connectivity is a critical issue in WSNs. If any node in the network can interact with other active node utilising intermediary nodes as relays, the network is connected. Once the sensors are installed, they form a network that should be linked in order for the data obtained by sensor nodes to be sent to data drains or controllers. In wireless sensor networks, reference [14] explored how to employ minimum nodes to maintain coverage and connectivity of the detection range. OGDC is a distributed geometric density control algorithm developed by Reference [14]. This method has three states for sensor nodes: UNDECIDED, ON, and OFF. The lifetime of a network is made up of numerous phases. Only parts of nodes remain in the ON state during each period due to information sharing between nodes, which effectively reduces the network's energy usage. At the same time, OGDC proposes a set of avoidance restrictions in order to avoid network node channel conflicts. However, OGDC is only useful if the node's communication distance is equal to or higher than 2 times the sensing radius, and the algorithm requires users to select too many parameters based on the network's specific conditions.

Reference [15] explored the coverage and connectivity challenges in sensor networks under the assumption that the sensing range is configurable, based on the OGDC algorithm in [14]. Reference [15] evaluated the energy usage of nodes in network coverage areas with fixed sensing ranges versus nodes with multiple sensing ranges. Reference [15] further indicates that the network with flexible perception range do save energy than the network with fixed perception range only when the perceived power consumption is 4 times proportionate to the sensing radius.

[16, 17] suggested a distributed linked coverage algorithm. The algorithm's goal was to reduce the number of active nodes to save energy and extend the network's lifespan. The primary idea behind this approach is to build a network's dominating set, and then use periodic reconstruction of the dominating set to effectively extend the network's lifetime. The coverage problem was examined in reference [18] under the assumption that the sensing and communication ranges of nodes in the network may be modified. The paper offered four techniques to tackle this problem: a distributed algorithm based on Voronoi graph partitioning, a centralised greedy algorithm, a distributed greedy algorithm, and a centralised approach based on Steiner tree, respectively. The connected coverage problem was studied in reference [19] when the sensing and communication ranges of nodes were both fixed. This study proposes three strategies to tackle this problem: a centralised greedy algorithm, a distributed greedy algorithm, and a distributed approach that takes node priority into account.

4.2.Point Coverage

Cover every point pi in P in the area aiA of certain sensor siS, which is chosen by mapping, given a set of points P with components pi denoted as (xi,yi). C. M. Cardei et al. [18] proposed a method for prolonging the lifetime of a sensor network while maintaining target point coverage. In this diagram, the sensor nodes are split into different set covers. Each set cover is activated in its own round and is able to cover all sensor network target points. Data is collected by each set cover and forwarded to an access point for further analysis. The authors provide two different solutions, one based on the linear programming and one on the greedy method. Simulations are used to validate the proposed methodologies.

4.3.Barrier Protection

All crossing paths bi are included in the area aiA of certain sensor siS, which is selected by mapping C, given a belt region B. Any path bi that completely covers the extent of the belt region B is referred to as a crossing path bi. A belt zone B is a long, narrow section with limited breathing space.

A. Chen et al. [17] presented the Localized Barrier Coverage Protocol. (LBCP). By delivering barrier coverage of its area, the sensor node cannot determine whether barrier coverage is provided for the full strip. This strategy is predicated on the notion that if the target's position changes, it will travel a shorter distance across the belt zone. As a result, if something changes in the belt zone, the sensor node would notice it. Local barrier coverage is shown to offer barrier coverage for the whole belt area if the belt area is large enough.

P. Balister et al. [18] introduced a new method for reliably estimating intensity in a fixed-size region that comprises thin strips. This method can also be used to provide reliable measure based for barrier coverage and network connection in a belt-shaped region. Sensor nodes act as a barrier, allowing variations in the target's position to be detected. The use of modeling confirms the accuracy of the results. Simulation results show that estimates derived using the suggested technique are accurate for small areas.

4.4.Protocols for Coverage-Aware Deployment

The greatest sensors are those that understand their coverage. Deployment is the process of determining the optimum locations for sensors in a network area in order to meet the coverage requirements of an application. A sub-problem in deployment protocols [19] is the coverage hole problem. It has to do with finding locations that aren't covered by any sensors. To address this issue, mobile sensors modify their location to fill in monitoring gaps and so increase the area covered [20]. The Highest Covering Sensor Deployment Issue (MCSDP) is a deploying problem in which the goal is to find the least number of sensors required to achieve maximum surveillance coverage. Most deployment problems are NP-hard problems with multiple competing aims. As a result, central evolutionary approaches are commonly utilised to solve a variety of deployment difficulties [21]. The deterministic point covering deployment problem in WSNs is addressed in [12] by PSODA, a PSO-based deployment strategy. In PSODA, the MCSDP is stated as a restricted optimization problem with the primary goal of reducing the number of sensors while maintaining coverage limitations for all target sites. The ROI is split into discrete cells, with each cell's centre acting as a potential sensor location. For each place in the network region, PSODA has a binary 0/1 decision variable, with 1 suggesting a sensor should be put there and 0 indicating it should not. The fitness value is a weightedsum approach that combines two sub-objectives: reducing the number of sensors required and reducing coverage constraint dissatisfaction. PSODA assumes that all sensors are static and homogeneous, as well as conforming to the Elfes sensing paradigm. To address the standard PSO's premature convergence problem, a modified PSO with a novel position updating mechanism was developed. PSODA was created to answer the problem of point coverage, but it may also be utilised for applications that demand full coverage of a region. It's worth noting that the PSODA protocol ignores the connectivity of the sensors and the BS.

To overcome the deterministic deployment problem in WSNs, [16] proposes a constraint Pareto-based Multi-objective Evolutionary Approach (CPMEA). Unlike PSODA, CPMEA considers coverage to be a target rather than a limitation. Furthermore, by modelling the connectivity need as a constraint, CPMEA seeks to ensure full communication between every sensor node and the BS. The objective functions in CPMEA are formulated using the Pareto dominance idea. The key goal is to develop many Pareto-optimal sensor configurations that can simultaneously increase coverage and lifespan while retaining full sensor communication. The desired placements of the sensor nodes are represented by the decision variables in CPMEA. The initial population is formed in two phases, rather than as a group of randomized layouts without regard for connectivity. The first stage is to create a variety of non - dominated sorting topologies that interconnect the BS and the sensor nodes. The placements of sensor nodes are then created at random depending on the BS location and the tree structure in the second stage. CPMEA presupposes that all sensors are stationary and homogeneous, and that they obey the boolean sensing model.

[23] presented a GA-based deployment mechanism to verify that a particular set of targets is covered and connected. The protocol's purpose is to pick the smallest number of possible sensor placements that satisfy two criteria: k-coverage and m-connectivity. The optimal solution was defined as a weighted combination of three scaled sub-objectives: minimising deployed sensor nodes, maximising total accomplished coverage, and maximum connectivity. The length of each GA individual is equal to the amount of possible sensor sites. A value of 1 or 0 can be assigned to each gene to indicate whether or not a sensor should be positioned at that particular region. [23] assumes the sensing range is the same as the transmission range and that all sensors use the boolean sensing paradigm. All of the sensors are also considered to be static and uniform.

Finding an optimal deployment pattern is another way to solve the channel assignment problem in WSNs. The ROI is segmented into virtual grids in this manner, and each sensor is placed at the intersection locations of the grid. The grid can be square, triangular, hexagonal, or any other shape. The deployment protocol's purpose is to determine the pattern (grid form) and the best sensor distance. The authors of [20], for example, devised a technique to solve the challenge of determining a periodic node deployment strategy that uses the fewest amount of sensors while yet providing k-coverage and connectivity. The suggested protocol's fundamental idea is to identify a distribution pattern that meets three criteria: the entire network is k-covered, the sensor networks are m-connected, and also the quantity of deployed sensors is kept to a minimum. This protocol's major purpose is to estimate sensor positions and ideal distances for 3 distinct distribution patterns: triangle, square, and hexagon. The protocol then decides on a deployment pattern that will allow the least amount of sensors to be deployed while still achieving coverage and connectivity requirements. All sensors are static and uniform, and the protocol assumes a boolean sensing paradigm.

Another method for coverage-aware distribution is to deploy and move mobile sensors to satisfy a specific application's coverage requirements. MobiBar [24] is a proposed protocol enabling barrier coverage applications of this type. MobiBar is a distributed deployment strategy that makes use of mobile sensors to create k separate complete barriers, resulting in k-barrier coverage. By moving the mobile sensors, the MobiBar protocol aims to produce a final deployment that gives the most possible barrier coverage. A baseline, according to the authors of MobiBar, is a line parallel to the network area's border that other obstacles should be built parallel to. MobiBar presupposes that sensors on nearby barriers can communicate with one another. The connected barrier component refers to these interconnected barriers. MobiBar assigns a priority to each barrier, which lowers as the gap between both the standard and the barrier grows. To increase the network's connectedness, all sensors move towards the baseline at first. The first sensor to attain the baseline chooses itself as the barrier component's leader. The leader then selects up to four neighbour sensors, each of which moves to a barrier position adjacent to the current one. Barriers with higher priorities are given priority. Each of the freshly moved sensors then repeats the process with up to four of its neighbours. If a relocated node cannot detect enough adjacent sensors to request relocation, it continues to do a restricted multihop search until one or more are found. If a relocated sensor discovers a barrier with a higher priority, it can only reposition itself to that barrier. By moving the sensors in the current barrier to the unoccupied spots of the older barrier, newer barriers are blended into older barriers. At the end of the process, a single connected barrier is created. MobiBar requires a boolean sensor model for sensing and a perfect disc model for communication, and all sensor nodes are mobile.

[25] presented a Mobile Sink (MS) based Coverage Optimization and Linkstability Estimation Routing (MSCOLER) protocol to I recover network coverage and ii) avoid transmission faults. MSCOLER has two modes of operation. MSCOLER moves the mobile sensors near the coverage holes during first cycle using a Grid-based Firefly Simulated Annealing (GFSA). To do the same, the networks is organised into grids, with at least one sensor monitoring each cell in each grid. With the goal of maximising the coverage ratio, the coverage problem is modelled as a nonconstrained optimization problem. The challenge is then solved using Firefly Simulated Annealing (FSA), which locates the best places for mobile sensors to restore coverage gaps. A Link Stability Estimation Routing (LSER) method is utilised in the second phase of MSCOLER to determine the best relay sensors for forwarding data to the BS. Expected Transmission Time (ETX), Received Signal Strength Indicator (RSSI), and Link Quality Indicator (LQI) are the three link quality metrics that are minimised to find the best links (LQI). The authors use a first-order energy consumption model and a binary sensing model. All of the sensors are similar in appearance, are movable, and are aware of their surroundings..

Coverage Protocol	Year Published	Main Goal(s)	Sensing Model	Location Awareness	Protocol Characteristics Dist.	Cent.	EC.
[17]	2015	Provide full area *K*-coverage/*M*-connectivity	Boolean	N/A	✗	✓	✓
[38]	2015	Provide full area *K*-coverage/*M*-connectivity	Boolean	N/A	✗	✓	✗
MobiBar [39]	2017	Provide *K*-barrier coverage	Boolean	Yes	✓	✗	✗
PSODA [37]	2016	Solve the MCSDP/Point coverage	Elfes	N/A	✗	✓	✓
CPMEA [16]	2016	Provide full area coverage/connectivity	Boolean	N/A	✗	✓	✓
MSCOLER [40]	2018	Provide targeta K-coverage/connectivity	Boolean	Yes	✗	✓	✓

Comparison of coverage aware deployment protocols

5. CONCLUSION

In wireless sensor networks, coverage is a key problem. Coverage, connectedness, and active node minimization are all investigated together in general. By giving practical data, various limits in sensor node design were explored in this research. The coverage issue was then explored, with its 3 kinds of coverage being discussed: area, point, and barrier coverage. The topic of area coverage was thoroughly examined, with research papers classified by node and distribution type, transmission and detection range, full coverage detection, and location based techniques. After that, some sensor network implementations were discussed.

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