# STUDY ON COVERAGE PROBLEMS IN WIRELESS SENSOR NETWORKS

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**Abstract:** In Wireless Sensor Networks Coverage problem is an important concern, which has a great consequence on the performance of wireless sensor networks. Given a sensor network, the coverage problem is to define how well the sensing field is supervised or traced by Wireless sensors. In this paper, we classify the various categories of coverage and detailed description of different algorithms.

***Keywords: Wireless sensor networks, Coverage problems, Target, Sensor.***

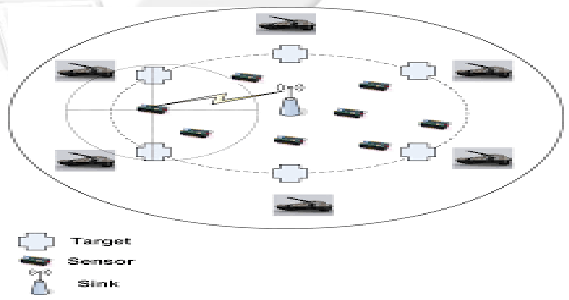
## I. INTRODUCTION

Through the greatprogress of wireless communication and embedded micro-sensing technologies, wireless sensor networks (WSNs) become more popular today. WSNs are composed of a large amount of low-cost and low-energy nodes that communicate with each other through single-hop or multi-hop wireless links. WSNs can be applied to battle field surveillance, home application, smart space, inventory tracking and biological detection [1, 2]. A basic and important function of WSNs is to monitor areas or targets for a long period, such as battlefield, fire monitoring and environment detection. Then, collect the useful data in the monitor areas, and then send the data to the base station or the sink. Since sensors are often deployed in remote or inaccessible environments and often spread in an arbitrary manner, a critical issue in the WSN applications is the coverage problem [3,5]. The purpose of this paper is to review the recent progress in this direction. Given a sensor network, the coverage problem in general is to determine how well the sensing field is monitored or tracked by sensors. Coverage problem is a fundamental problem in wireless sensor networks, a lot of works have been dedicated to the coverage-related problems in WSNs for many years. These include the surveillance and the concerns of coverage versus connectivity issues when deploying a sensor network. Although some other works are targeted at particular applications, but the central idea is still related to the coverage problem. Since the energy of sensors is limited and it is impossible to replace them, how to conserve the energy of the sensors and prolong the network lifetime while guaranteeing the coverage of areas or targets is an important issue in the applications of WSN.

In the applications of wireless sensor network, a good coverage algorithm can better support MAC protocol and routing protocol in the network. Satisfy the requirements of the coverage and extend the network lifetime is an important issue in WSNs. Many coverage algorithms can be found in recent years, but there still exist many problems in these algorithms. In this paper, we study the target coverage problem under the stochastic model in wireless sensor network. By effectively scheduling the sensors in the network after deployment to fully cover all the targets and prolong the network lifetime.

## II. CLASSIFICATION OF COVERAGE PROBLEMS

Different coverage algorithms have been proposed in recent years in static WSNs, that is to say, the sensor nodes do not move once they are deployed. The coverage algorithms often based on the subject to be covered (area versus discrete points), sensor deployment mechanism (random versus deterministic) as well as other wireless sensor network properties (e.g. minimum energy consumption and network connectivity). In this paper, we survey recent works into three types: area coverage, point coverage and barrier coverage [6]. Area coverage problem is the popular coverage problem in WSNs, and is widely studied for many years, where the main objective of the sensor network is to cover or monitor an area or sometimes referred as region. Under the condition that any sensor node can be covered in the monitoring area, area coverage aims at how to schedule the sensor nodes in the network, so as to maximize the network lifetime.




Barrier coverage problem is to detect the probability of a moving object be found when crossing the deployment region of wireless sensor networks. We consider the barrier coverage as the coverage with the goal of minimizing the probability of undetected penetration through the barrier (sensor network).

## III. OVERVIEW OF COVERAGE PROBLEMS

In the point coverage problem, the objective is to cover a set of points (targets). Under the condition that all the targets can be covered in the monitoring area, point coverage aims at how to schedule the sensor nodes in the network, so as to maximize the network lifetime. The black nodes form the set of active sensors, the result of a scheduling mechanism. Network coverage problem is centered on a fundamental question: how well do the sensors observe the physical space The coverage problem is an important measure of the quality of service (QoS) of the wireless sensor networks. In this section, we divided the coverage algorithms into three typical types: area coverage, point coverage and barrier coverage. We will discuss these algorithms in detail in the following.

### 1. Area Coverage

Area coverage mainly ensures that the whole area is fully covered, i.e. each point in the area of can be covered. According to different requirements of area coverage, the existing coverage algorithms can be divided into 1-coverage algorithms, k-coverage algorithms and connected-based coverage algorithms.

***a) Coverage Algorithms:*** In this section, we present several efficient area coverage mechanisms. Reference [7] presented a distributed algorithm named PEAS, which was a control algorithm based on node density detection. In PEAS, nodes worked in a round mechanism. At each round, nodes had two stages: an environmental detection phase and an adaptive phase. Firstly, the sensor nodes were in a sleep state, and then, the sensor nodes were awakened after a random time interval. The active nodes would detect if there were any survival nodes in their sensor range. If so, the node would go to a sleep mode; if not so, the node would enter the working state. PEAS can adjust the detection range and the wake-up intervals to ensure the quality of coverage in wireless sensor networks. Although PEAS did not need the accurate geographic information of nodes, and the cost of algorithm is not too big, but PEAS cannot guarantee that the region can be completely covered. Reference [8] presented a distributed node scheduling mechanism, which can run on each sensor node. The algorithm can analyse the possibility of one node becoming a redundant node according to the relationship of the positions of different nodes. If a node is a redundant node, it will sleep. The algorithm judged the redundant nodes only considering the neighbour nodes in its sensing range, while, there are still other redundant nodes in active nodes, thus, the performance of this mechanism need to be enhanced. The reference [9] considering the mechanism proposed in [8] demanding to know the position information of nodes precisely, so, aimed at the area need not to be complete coverage, reference [9] proposed three node scheduling algorithm: node scheduling algorithm based on the number of neighbours, the scheduling algorithm based on nearest neighbour and the scheduling algorithm based on probability.

***b) k-Coverage Algorithms :*** In some important environmental monitoring application systems [10], such as fire, gas leakage, explosion and other monitoring systems, 1-coverage algorithms cannot meet the requirements of different applications. So, some researches start the study of k- coverage problem. The reference [11, 12] provided a centralized k- decision algorithm, it only need to detect whether arbitrary nodes in the perimeter of the sensing disk can be covered by other k nodes, and then, the mechanism can determine if all the region is k- covered. However, the algorithm is a centralized algorithm and the complexity of this algorithm is too high. In large-scale WSN applications, Sink need to do too many calculations, so, the performance of the algorithm is not so good. The mechanism presented in reference [13] is a k-coverage configuration protocol, which ensured that if any point within the intersection area of sensing disk can be k-covered, then the entire region also can be k-covered. However, the mechanism did not consider the contribution value of the network when the node from the sleep state changing to the active state, which leads to a low efficiency of network coverage and a larger redundancy degree of nodes.

***c) Connected-Based Coverage Algorithms:*** An important issue in WSNs is connectivity. A network is connected if any active node can communicate with any other active node, possibly using intermediate nodes as relays. Once the sensors are deployed, they organize into a network that must be connected so that the information collected by sensor nodes can be relayed back to data sinks or controllers. Reference [14] discussed how to use the minimum nodes to maintain the coverage and connectivity of the monitoring area in wireless sensor networks. Reference [14] also designed a distributed geometric density control algorithm named OGDC. Sensor nodes have three states in this algorithm, namely UNDECIDED, ON and OFF state. The network lifetime composed of many periods. In each period, through the exchange of information between nodes, there are only parts of nodes in the ON state, which can effectively reduce the energy consumption of the network. At the same time, in order to avoid channel conflicts of nodes in the network, a series of avoiding regulations are proposed in OGDC. But, OGDC is only applicable in the condition that the communication distance of the node is equal to or greater than 2 times of the sensing radius, and the algorithm need users to set too many parameters according to the specific network condition. Based on OGDC algorithm in [14], reference [15] discussed the coverage and connectivity problems on the condition that the sensing range is adjustable in sensor networks. Reference [15] also compared the energy consumption of nodes in network coverage area when the sensing range of node is fixed and node has multiple sensing ranges. Reference [15] also shows, only when the perception energy consumption is 4 times proportional to the sensing radius, the network with adjustable perception range can save more energy than the network with fixed perception range. A distributed connected coverage algorithm was proposed in [16, 17]. The algorithm aimed to minimize the number of active nodes in order to save energy and prolong the network lifetime. The basic idea of this algorithm is to construct a dominating set of network, through the periodic reconstruction of the dominating set, the mechanism can effectively prolong the network lifetime.

In [18] the coverage problem under the circumstances that the sensing range and communication range of nodes can be adjusted in the network. In order to solve such problem, the paperproposed 4 algorithms respectively: a distributed algorithm based on Verona graph partitioning, a centralized greedy algorithm, a distributed greedy algorithm, and a centralized algorithm based on Steiner tree. In [19] studied the connected coverage problem when the value of sensing range and communication range of nodes is fixed. In order to solve this problem, 3 algorithms were proposed in this paper: a centralized greedy algorithm, a distributed greedy algorithm, and a distributed algorithm considering node priority.

**2. Point Coverage**

In the point coverage problem, the objective is to cover a set of points. The point coverage problem considers how to maximize the network lifetime on the condition that all the objectives in the monitoring area are covered. In many practical applications of wireless sensor networks, such as the monitoring in forest fires and nuclear leakage, we can abstract them into the point coverage problem in wireless sensor networks, so the research on target coverage problem is very important. According to different requirements of target coverage problem, this paper divided the target coverage problem into three parts: coverage problem without considering the target coverage algorithms, connected-based target coverage algorithms and directional target coverage algorithms.

***a) Point Coverage without Considering the Target Coverage Algorithms:*** Reference [20] constructed a continuous disjoint sets, each time selected the sensor nodes which can cover as many targets as possible to form the sets. Although the mechanism in [20] can ensure that all targets are covered in the network, but the mechanism has a very strict restriction, that is, the construction of the sets in each time must be disjoint. In order to enhance the shortage of mechanism in [20], G-MSC algorithm in reference [21] constructed the continuous intersection sets to extend the network lifetime. The algorithm does not have the constraints that each set must be disjoint. For example, a node can appear in many different node cover sets. However, when G-MSC algorithm evaluates the contribution of nodes, it only consider the number of uncovered targets which fall in its sensing range, which made some nodes are selected preferentially and easily to die. As reference [20, 21] did not consider that the sensor nodes may have many different sensing ranges in actual wireless sensor networks, therefore, reference [22] first studied the target coverage problem with multiple sensing range, discussed how to schedule nodes and their sensing ranges to ensure all objectives be covered at least once in the network, and then effectively prolonged the network lifetime. This paper also proved that the problem is a NP complete problem. In order to solve this problem, reference [33] provided a centralized algorithm named CGH and a distributed algorithm DLGH. CGH algorithm always selected the node and its sensing range with the largest contribution to construct the intersect set, which made the node with the largest contribution was always easily to die, and there were too many redundant nodes appeared in the set of the working nodes in every round. DLGH only used the information between its one hop neighbours to determine its sensing range resulting, which resulted in too many redundant nodes appeared in each round.

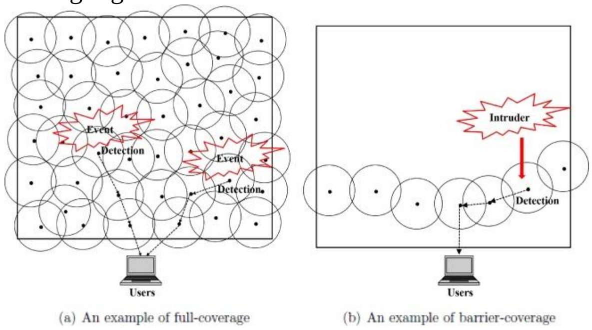
Reference [23] discussed how to maximize the network lifetime when the deployment environment of the network was safe and controllable, which guaranteed all the network targets had been coverage and the network was connected. Reference [24] assumed that the network is homogeneous, i.e. the sensing radius of the node in the network was equal and the communication radius of node was just equal to the value of sensing radius. Then, the paper proposed a polynomial approximate algorithm, which better improved the performance of the network, and the algorithm is based on minimum spanning tree. A new analysis method of target coverage in wireless sensor networks was presented in [24] this method used the Clifford algebra to represent the targets in the network, and then presented a solution to calculate the coverage ratio of the network. Based on this calculation method, reference [24] proposed a maximum clearance routing algorithm in wireless sensor network. The relationship between nodes and targets in wireless sensor networks was discussed in [25], and then, a target coverage algorithm named MTACA for multi-objective associated was proposed. The algorithm considered energy efficiency of sensor nodes, through mining the relationship between sensor nodes and the targets to determine the working nodes. In addition, reference [25] also improved PEAS algorithm, which improved the effectiveness of PEAS algorithm. Reference [26] studied the k-target coverage problem in wireless sensor networks, presented an algorithm that did not require location information of the node. Based on a mathematical model presented in [26] and the ratio of node's sensing radius to monitoring area, the algorithm could know how many sensor nodes needed to cover the monitoring area. The algorithm could greatly reduce the cost of hardware in the network and improved the QoS of the network. Reference [27] analysed k-target coverage problem under random deployment model, and the paper put forward a target coverage algorithm based on the track of nodes. This mechanism could make all targets in the network be covered by at least k nodes, and could prolong the network lifetime effectively. According to target location and the dispersal track of sensor nodes, as well as mutual cooperation between nodes, the algorithm could realize the k-target coverage of network.

***b) Connected-Based Point Coverage Algorithms:*** Reference [28] studied connected target coverage problem in wireless sensor network, and designed a distributed algorithm, which did not need the global information of WSN, the mechanism only need the information of 3-hops neighbours to realize the coverage and connectivity. The algorithm is especially suitable for intensive large-scale wireless sensor networks. Reference [29] presented a connected target cover algorithm when sensor nodes have multiple sensing ranges. The algorithm firstly constructed a virtual skeleton, all the nodes are connected with one node in the virtual skeleton or the node is just in the virtual skeleton, then the algorithm considered how to cover all targets in the network. This algorithm had a defect that the construction of connected virtual skeleton in many sensor network applications was often not necessary. Reference [30] considered the energy for data receiving and data transmission of nodes in energy model, but did not consider how does the data be transmitted to the sink, and only considered using other routing mechanisms to achieve. On the basis of reference [30], the algorithm in [31] modelled the connected target coverage (CTC) problem as a maximum cover tree (MCT) problem, and also proved that MCT is a NP-complete problem, and then gave an upper bound solution for MCT problem. Then, it developed an approximate algorithm named App_MCT and a greedy algorithm named CWGC. The basic idea of CWGC algorithm is to give each node and edge in the network a weight value, and then greedily choose proper nodes and edges to build a cover tree to execute the work task in each round. Finally, reference [31] used the extensive simulations to demonstrate the effectiveness of the App_MCT algorithm and CWGC algorithm.

***c) Directional Point Coverage Algorithms:*** Reference [32] discussed the point coverage problem in wireless sensor network, and proposed two distributed algorithms and one scheduling protocols, namely, EDO, EGA and NSS. EDO algorithm took priority to critical coverage points, and then selects the direction with largest contribution as the direction of working nodes. EGA algorithm selected the direction of sensor nodes which can cover as many uncovered targets as possible as the direction of the working sensor nodes. The NSS protocol introduced the concept of local coverage set. By judging whether the node was a redundant node in the network, NSS protocol could make part of nodes in the network to go to sleep, which can maximize the network lifetime. The algorithm in [33] discussed the target coverage problem in directional wireless sensor networks, and designed one direction adjustable perception model, and then, proposed a virtual market based cover growth algorithm named PECEA. The algorithm converted the coverage enhancement problem into a uniform distribution problem to eliminate the sensing overlapping area and blind area of the network, so as to realize the whole coverage in directional sensor networks.

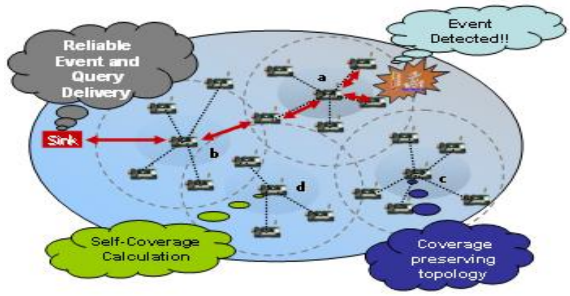
## 3. Barrier Coverage

Barrier coverage is the coverage with the goal of minimizing the probability of undetected penetration through the barrier (sensor network). Barrier coverage studies the perceived probability of moving target through the deployment region of wireless sensor networks. The meaning of this problem is, on one hand, one should choose one safe path as much as possible when cross the enemy monitoring area; on the other hand, the mechanism can determine the optimal deployment of the network to make the mobile target have a high probability to be detected. Reference [34] studied how to find the maximum crack path and the maximum support path in polynomial time; they respectively corresponded to the network in the worst and the best situation to cross the monitoring region.




(a) An example of full-coverage (b) An example of barrier-coverage

Reference [35] discussed how to find the minimum and maximum exposure path, which are the monitoring time of targets. On the basis work of [35], reference [36] presented a density control algorithm based on probability coverage model. The algorithm could guarantee the network have a good coverage ability. By reducing the number of redundant nodes in the network, the detection time of the network had been extended. A fixed algorithm based on foreign coverage and position discovery was presented in [37]. Reference [38] presented a target localization algorithm in wireless sensor networks; this algorithm could obtain the geographic information of mobile target in the monitoring area of wireless sensor networks.




Reference [39] studied the requirements of full coverage and connectivity of active nodes sets which were chosen by CDS selection method. Barrier coverage problem was discussed in [40]. Reference [41] classified various blind areas in wireless sensor network, and analysed the characteristics of different kinds of blind areas, such as coverage blind area, routing blind area, interference blind area, and worm blind area. Reference [42] discussed the target detection problem in grid deployment and randomly deployed network. A penetration theory algorithm was presented in [43]. By measuring the density of the critical point, the algorithm could find the path information, for example, when the density of node was less than the density of outside environment, there must one path existing could not be found. In addition, a binary perception model and a probability sensing model were discussed in [42] respectively; the coverage ratio relationship of node distribution which satisfied the Poisson process in random wireless sensor network was discussed in this paper.

# IV. CONCLUSION

In this paper, we categorized and described recent coverage problems proposed in static wireless sensor networks. Sensor coverage problem is an important factor for QoS in applications in WSNs. Coverage and connectivity are associated with each other, and coverage and connectivity are two important properties of a WSN. Existing studies show that adjusting the working directions of sensor nodes is the main method for coverage improvement, whereas scheduling sensor nodes has been proposed to prolong the network lifetime. There are both centralized and distributed coverage algorithms in WSN, distributed algorithms are more scalable for large sensor networks, and distributed solutions do not need global information, the sensor nodes in distributed algorithm only exchange messages with their neighbouring nodes. Thus, the required communication overhead for organizing the working directions is lower than the centralized solutions.

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