



A Survey on the Coverage of WSNs

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Abstract : *Wireless sensor networks address a broad range of applications related to national security, surveillance, military, healthcare and environmental monitoring. They are rapidly growing area for research and commercial development. One of the most active areas of research in wireless sensor networks is that of coverage. Coverage in wireless sensor networks is usually defined as extent or degree to which something is observed, analyzed, and reported. The coverage problem has been extensively studied in recent years. In this paper, we take a representative survey of the work that has been done in the area of coverage. Several terms and concepts have been defined and then shown how they are being utilized in various research works. We also provide a brief summary and comparison of different types of coverage.*

Keywords: *Coverage, wireless sensor network, nodes, deployment strategy, survey.*

I. INTRODUCTION

A WSN typically has little or no infrastructure. It consists of thousands of sensor nodes, deployed either randomly or according to some predefined statistical distribution, over a geographic region of interest. A sensor node by itself has severe resource constraints, such as low battery power, limited signal processing, limited computation and communication capabilities, and a small amount of memory; hence it can sense only a limited portion of the environment. However, when a group of sensor nodes collaborate with each other, they can accomplish a much bigger task efficiently. One of the primary advantages of deploying a wireless sensor network is its low deployment cost and freedom from requiring a messy wired communication backbone, which is often infeasible or economically inconvenient. WSNs have great potential for many applications in scenarios such as military target tracking and surveillance, natural disaster relief, biomedical health monitoring, and hazardous environment exploration and seismic sensing. In military target tracking and surveillance, a WSN can assist in intrusion detection and identification. Specific examples include spatially-correlated and coordinated troop and tank movements. With natural disasters, sensor nodes can sense and detect the environment to forecast disasters before they occur. In biomedical applications, surgical implants of sensors can help monitor a patient's health. For seismic sensing, ad hoc deployment of sensors along the volcanic area can detect the development of earthquakes and eruptions. A sensor network can be deployed in a remote island for monitoring wildlife habitat and animal behavior, or near the crater of a volcano to measure temperature, pressure, and seismic activities.

The WSNs can be categorized as: structured and unstructured. An unstructured WSN is one that contains a dense collection of sensor nodes [4]. Once deployed, the network is left unattended to perform monitoring and reporting functions. In an unstructured WSN, network maintenance such as managing connectivity and detecting failures is difficult since there are so many nodes. In a structured WSN, all or some of the sensor nodes are deployed in a pre-planned manner. The advantage of a structured network is that fewer nodes can be deployed with lower network maintenance and management cost. Optimal resource management and assuring reliable Quality of Service (QoS) are two of the most fundamental requirements in ad hoc wireless sensor networks. Sensor deployment strategies play a very important role in providing better QoS, which relates to the issue of how well each point in the sensing field is covered. However, due to severe resource constraints and hostile environmental conditions, it is nontrivial to design an efficient deployment strategy that would minimize cost, reduce computation, minimize node-to-node communication, and provide a high degree of area coverage, while at the same time maintaining a globally connected network is nontrivial.

Different applications would require different degrees of coverage in the sensing field. Thus, the coverage requirements vary across applications and should be kept in mind while developing new deployment strategies. In the simplest term, the degree of coverage at a particular point in the sensing field can be related to the number of sensors whose sensing range cover that point. There are several factors that must be considered when developing a plan for coverage in a sensor networks. Many of these will be dependent upon the particular application that is being addressed. The capabilities of the sensor nodes that are being used must also be considered. The different types of coverage that have been covered in this paper are:

1. *Blanket/Area coverage* — the main objective of the sensor network in area coverage is to cover (monitor) a region (the collection of all space points within the sensor field), and each point of the region need to be monitored.

2. *Point Coverage* — the objective is to cover a set of point (target) with known location that need to be monitored. The point coverage scheme focuses on determining sensor nodes' exact positions, which guarantee efficient coverage application for a limited number of immobile points (targets). Generally, it can be solved as a special case of the area coverage problem when sensor nodes' number may leave out of account.

3. *Target coverage* — Considered as number of targets with known location that needs to be continuously observed (covered) and a large number of sensors closely deployed to the target.

4. *Barrier coverage* — Barrier coverage refers to the detection of movement across a barrier of sensors. This is useful in applications where the major goal is to detect intruders as they cross a border or as they penetrate to a protected area.

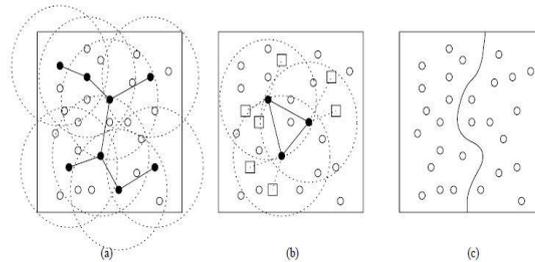


Fig. 1 (a) Area coverage, (b) point coverage, and (c) barrier coverage.

Figure (a) shows random deployment of sensors to cover a given area. Figure (b) shows a set of sensors randomly deployed to cover a set of points. Figure (c) shows a barrier coverage problem (start and end points of the path are selected from bottom and top boundary lines of the area).

The rest of the paper is organized as: Section II describes the different deployment stages considered for different types of coverage viz. area coverage, point coverage, target coverage and barrier coverage. In section III a comparison of different types of coverage is provided. Section IV concludes the paper.

II. COVERAGE TYPES AND DEPLOYMENT STRATEGIES

A. Area Coverage

Deployment of a wireless sensor network is determining what it is exactly that you are attempting to monitor. Area Coverage i.e. coverage of an entire area also known as full or blanket coverage means that every single point within the field of interest is within the sensing range of at least one sensor node. It helps to achieve a static arrangement of sensor nodes that maximize the detection rate of targets appearing in the sensing field. Generally, the minimum number of sensor nodes is deployed within a field in order to achieve blanket coverage. The problem was addressed in [5], where the author proposes placing the nodes in a construct called an r -strip such that each sensor is located r distance away from the neighboring sensor where r is the radius of the sensing area. The strips can be then placed in an overlapping formation such that blanket/area coverage is achieved.

A node-scheduling scheme discussed in [3] can reduce system overall energy consumption, therefore increasing system lifetime, by turning off some redundant nodes. Their coverage-based off duty eligibility rule and back off-based node-scheduling scheme guarantees that the original sensing coverage is maintained after turning off redundant nodes. They have implemented the proposed scheme in NS-2 as an extension of the LEACH protocol. We compare the energy consumption of LEACH with and without the extension and analyze the effectiveness of our scheme in terms of energy saving. The preservation of the system coverage to the maximum extent is achieved. In addition, after the node-scheduling scheme turns off some nodes, certain redundancy is still guaranteed, which is believed to provide enough sensing reliability in many applications.

Since sensor networks contain a large number of sensor nodes, the nodes must be deployed in clusters, where the location of each particular node cannot be fully guaranteed in prior. In networks with stochastically placed nodes, activating only the necessary number of sensor nodes at any particular moment can save energy. A heuristic that selects mutually exclusive sets of sensor nodes, where the members of each of those sets together completely cover the monitored area is discussed in [11]. The intervals of activity are the same for all sets, and only one of the sets is active at any time. The experimental results demonstrate that by using only a subset of sensor nodes at each moment, a significant energy saving can be achieved while fully preserving coverage.

B. Point Coverage

In the point coverage problem, the main objective is to cover a set of points. Figure 1 (b) shows a set of sensors deployed randomly to cover a set of points, the connected black nodes form the set of active sensors. Next, the coverage approach for each sensor deployment method: random and deterministic is presented as Model 1 and Model 2 respectively.

1) Model 1: Random sensor deployment method, the sensor location is not known in prior. This feature is required when individual sensor placement is infeasible, for example battlefield or disaster areas. The point coverage scenario addressed in [6] has military applicability. The paper addresses the maximum disjoint set covers problem and designs a heuristic that computes the sets. Here, a limited number of points (targets) are considered where the location is known that need to be monitored. The approach used by author is to determine a maximum number of disjoint sets, so that the time interval between two activations for any given sensor is longer. The disjoint sets i.e. division of the set of sensors which completely covers all targets are activated successively, such that at any moment in time only one set is active. This approach extends the sensor network lifetime through energy resource preservation.

The whole scenario requires a large number of sensors distributed randomly with a central processing node (receives monitored information by the sensors) such that every target must be monitored at all times by at least one sensor, assuming that every sensor is able to monitor all targets within its sensing range.

2) Model 2: If the sensors can be placed exactly where they are needed, the corresponding deployment method is deterministic. The scenario where it is possible to explicitly place a set of sensor nodes is considered [5]. A minimum number of sensor nodes are determined and their location is covered over a given set of n points by connecting the deployed sensors. An approximation algorithm proposed by the authors begins by constructing the minimum spanning tree over the targeted points, and then successively selects sensor node locations on the tree such that the coverage and connectivity is maintained at every step. This is feasible in friendly and accessible environments where all sensors have the same sensing range and the sensing range equals the communication range, for which the performance ratio of 7.256 is calculated.

C. Target coverage

In target coverage, a fixed number of targets is observed. It has an obvious surveillance application. This section deals with the intrusion detection is a surveillance problem. In paper [1], the authors approach is based on a dense, distributed, wireless network of multi-modal resource-poor sensors combined into loosely coherent sensor arrays that perform *in situ* detection, estimation, compression, and exfiltration. The design space of sensors, signal processing algorithms, communications, networking, and middleware services is explored. The influence field is introduced, which is estimated from a network of binary sensors. The quantitative analysis of the effects of network unreliability on application performance is discussed. The key elements of this include detection, classification, and tracking. The estimator performance varies for different target classes and network reliability levels.

An efficient method to extend the sensor network life time by organizing the sensors into a maximal number of set covers that are activated successively is studied in [7]. By allowing sensors to participate in multiple sets, our problem formulation increases the network lifetime compared with related work that has the additional requirements of sensor sets being disjoint and operating equal time intervals. They have modeled the solution as the maximum set covers problem and design two heuristics that efficiently compute the sets, using linear programming and a greedy approach. Simulation results are presented to verify our approaches. Wireless sensor networks are battery powered, therefore prolonging the network lifetime through a power aware node organization is highly desirable. An efficient method for energy saving is to schedule the sensor node activity such that every sensor alternates between sleep and active state. One solution is to organize the sensor nodes in set covers, such that every cover completely monitors all the targets. These covers are activated in turn, such that at a specific time only one sensor set is responsible for sensing the targets, while all other sensors are in the sleep state. This problem is modelled as maximum set covers problem. They provide that problem is NP-complete and proposed two efficient heuristics, LPMSC and Greedy-MSC heuristics, using a linear programming formulation and greedy approach, respectively.

D. Barrier Coverage

Barrier coverage is an important issue in wireless sensor networks (WSNs), which guarantees to detect any intruder attempting to cross a barrier or penetrating a protected region monitored by sensor networks. The fundamental issue is to form sensor barriers such that the area covered by the sensors in a barrier can form a continuous fence for intrusion detection. The barrier coverage is considered as the coverage with the goal of minimizing the probability of undetected penetration through the barrier (sensor network). Figure 1 (c) shows a general barrier coverage problem. There are two types of barrier coverage models proposed here-

1) Model 1: The first model [9], deals with the problem maximal breach path (MBP) and the maximal support path (MSP) that corresponds to the worst/best case coverage and has the property that for any point on the path, the distance to the closest sensor is maximized/minimized. In this paper, the authors determine the initial and final locations of an agent that needs to move through the field, addresses a MBP and MSP of the agent over a given field instrumented with sensors. The model assumed by the authors is of homogeneous sensor nodes using GPS (with sensing effectiveness decreasing as the distance increases). The algorithm starts by generating the Voronoi diagram (or Delaunay triangulation

diagram), assigning each segment a weight equal with the distance to the closest sensor or equal with the segment length and then uses binary-search and Breadth-First-Search for path computation. A centralized solution was proposed based on the observation that coverage formulations and algorithms specifically determines that MBP lies on the Voronoi diagram lines and MSP lies on Delaunay triangulation lines.

The coverage problem is further explored and formalized in [12]. The distributed algorithm for computing MSP using the relative neighborhood graph is proposed. The authors also focused on two extensions of MSP, namely MSP with least energy consumption and MSP with smallest path distance.

Next, the number of sensor nodes is determined in [2] that are deployed randomly in the field such that the probability of a penetration path is close to zero. The coverage and detectability problem of grid-based sensor networks and random sensor networks is addressed. The authors proposed (based on percolation theory) a critical density for a given sensor networks, such that for nodes deployed with a lower density a penetrating path that will not be detected almost surely exists, whereas above this critical density any crossing object is almost surely detected.

2) Model 2: The second barrier coverage problem discussed is *exposure-based model* in [10]. The minimal exposure path provides valuable information about the worst case exposure-based coverage in sensor networks. The problem of determining the minimal exposure path has been considered. The longer the exposure time, the greater the sensing ability. The sensing model is defined by Euclidean distance between the sensor (s) and the point (p) and sensor technology dependent parameters (k). Another characteristic is the intensity of the sensor field. Further, the authors considered the problem of determining the minimal exposure path over a given field deployed with n sensors and the initial and final points of object. This path resulted to the worst-scenario. The solution was proposed using a grid-based approach to transform the problem domain to a tractable discrete domain as the exposure analytical computation is intractable. Each grid square with minimum exposure path is then restricted to line segments connecting any two vertices. The grid is converted to a weighted graph, where the weight of an edge corresponds to exposure, is approximated using numerical techniques. The Dijkstra's single source-shortest-path algorithm is further used to find the minimal exposure path between any two points (starting and ending points on the grid). The approximation provides an unbounded level of accuracy as a function of run time and storage.

The other aspect of the exposure-based model is pointed in [8]. In this paper, the critical number of nodes required for target detection in a sensor network is evaluated. The physical characteristics of sensor and target in evaluating the sensing capacity of sensor networks are incorporated. Such modeling enables sensor network design, where the user can decide the density of nodes to be used depending upon the target characteristics it is trying to detect as well the nature of sensor deployed. To estimate the sensor node deployment density, both the sensor characteristics as well as target specifications is considered. The authors have assumed that the target moves in a straight-line path, with constant speed, between two given points. For a given sensor, two radii are associated for a given sensor i.e. *radius of complete influence* (the distance from the sensor such that all targets originating within this radius are detected) and *radius of no influence* (the property that is defined as any target originating beyond it cannot be detected). The paper proposes a solution to calculate the influence radii as well as the sensor nodes deployment density using the sensing and exposure model, and knowing the threshold energy parameter required to detect a target.

III. ANALYSIS OF DIFFERENT DEPLOYMENT STRATEGIES

In this section, we provide a brief analysis of different deployment strategies for the different types of coverage viz. area coverage, point coverage, target coverage and barrier coverage in a tabular form as shown in table 1.

We also specify the objectives of these approaches respectively. The coverage approaches considered for area coverage and point coverage include *node self-scheduling algorithm, constrained-minimally constraining heuristic, node placement algorithm (minimum spanning tree algorithm), disjoint set cover heuristic*. The deployment strategy considered for target coverage include *bounding box heuristic using centroid approach, synchronization algorithm, logical grid routing protocol and linear programming MSC (maximum set cover) and greedy MSC heuristic*. Further, the coverage strategy/approach studied for barrier coverage includes *maximal breach path algorithm, maximal support path algorithm and node density -based coverage*.

It can be seen that apart from coverage, most of the work done in WSNs emphasizes on energy efficiency and maximization of network lifetime. Energy-efficiency is an important issue in WSNs, caused by limited battery resources. Mechanisms that conserve energy resources are highly desirable, as they have a direct impact on network lifetime. Network lifetime is in general defined as the time interval that the network can perform the sensing functions and transmit data to the sink.

TABLE 1: DIFFERENT COVERAGE APPROACHES

COVERAGE TYPE	APPROACH COVERAGE	COVERAGE OBJECTIVE
Area coverage	Node self scheduling algorithm	Energy efficiency, maximize network lifetime
Area coverage	Constrained –minimally constraining heuristic	Energy efficiency, maximize network lifetime

Area coverage and Point coverage	Node Placement Algorithms (minimum spanning tree-based algorithm)	Energy-Efficiency, Connectivity
Point coverage	Disjoint Set Cover Heuristic	Energy-Efficiency Maximize network lifetime
Target coverage	Bounding Box heuristic, Synchronization algorithm, Logical Grid Routing Protocol	Target Detection, time synchronization , tracking and connectivity
Target coverage	Linear programming MSC and Greedy MSC heuristic	Energy efficient, Maximized network lifetime
Barrier coverage	Minimum Exposure Path Algorithm	minimum exposure path
Barrier coverage	Maximal Breach Path and Maximal Support Path Algorithms	Worst and best case coverage paths
Barrier coverage	Maximal Support Path Algorithm	Best case coverage path
Barrier coverage	Node Density -based Coverage	critical node density

IV. CONCLUSION

Sensor coverage is an important element for QoS in applications with WSNs. Coverage is in general associated with energy-efficiency and network connectivity, two important properties of a WSN. In this paper accommodating a large WSN with limited resources and a dynamic topology is discussed. Various interesting formulations for sensor coverage recently proposed have been considered. To meet the intended objective, these problems aim at either deterministically placing sensors nodes, determining the sensor deployment density, or more generally, at designing mechanisms that efficiently organize or schedule the sensors after deployment with the different strategies as discussed above. In this paper we have surveyed the different types of coverage with different types of deployment strategies for each coverage type. We have summarized the different approaches/strategies in a tabular form.

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