

## Target Coverage and Network Connectivity Challenges in Wireless Sensor Networks

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### Abstract

Target Coverage and Network Connectivity in Wireless Sensor Networks (WSNs) plays a momentous role in the field of monitoring environment, habitant observing, disaster recovery, surveillance, etc. Coverage and Network Connectivity collectively can be considered as a proportion of Quality of Service (QoS) in a sensor network. It implies the coverage of each point in the detecting field while in the meantime fulfilling the measure that each node is surrounded by the equivalent neighbourhood of at least one other node. Many primary issues influence the outline and performance of WSN. A Comprehensive survey is made based on the scheduling algorithm and set cover approach, in which we analyze various approaches and their algorithm complexity. Firstly, the scheduling algorithm intermittently provides the required data service with guaranteed efficiency. This methodology can efficiently reduce the entire number of active nodes in the network, resulting in maximizing the network lifetime. Secondly, the set cover approach plays a major role in solving target coverage problem which group sensors into each cover set thereby, target coverage was achieved. Typical issues and open research challenges are addressed by classifying the approaches available in literature into three broad categories namely, adaptable coverage radius, coverage deployment strategy, and sleep scheduling. This survey aims to provide a better perceptive of the existing open challenges and possible futuristic approaches for target coverage and network connectivity in wireless sensor networks.

**Keywords:** Network connectivity, Scheduling algorithms, Set cover approach, Target coverage, WSNs.

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### 1. Introduction

In recent times, wireless sensor networks were applied in numerous fields, such as surveillance, sensing and observing with two primary objectives: target coverage and network connectivity. Network lifetime is considered as a vital factor to determine the performance of a sensor network; energy utilization should be lessened in sensor nodes due to the limited battery power. Various sensor techniques are used to improve the coverage as well as network connectivity. In a network, a single sensor cannot be able to monitor an entire region, so that a group of

sensors is deployed to exchange the information. The main objective of WSN is to guarantee the surveillance of a given set of targets with a limited number of sensors that transmit the detected information to the base station [1-5].

In general energy reduction approaches can be classified in the subsequent division: a) schedule the nodes either active or sleep mode, b) by adjusting the transmission range c) energy-efficient routing techniques and data gathering d) finally, reduce the amount of data transmitted. The target coverage is classified into static and dynamic based on the target characteristics such as; Static target coverage refers to the stationary targets. For example, soil moisture and temperature monitoring, forest

fire monitoring, etc., whereas dynamic target coverage refers to non-stationary targets such as linear and curvilinear movement, uniform and variable movement. For example intruder detection, etc. Major Challenges that influence the performance of a wireless sensor network are Hardware and Operating system, Deployment, Synchronization, Localization, Calibration, Network, and Transport Layer issues, Database Centric Challenges and Querying, Middleware, Quality of Service issues and Security. Among these challenges, the current work focuses on QoS. Quality of service is measured in terms of target coverage and network connectivity in the networks. Thus, the quality of network guarantees that the detected information from every sensor will be capable of being conveyed to the base station and the quality of the target coverage guarantees that the entire observed field is secured with the coverage measure[6-7].

Target coverage and connectivity are considered in terms of Quality of Service, thereby connected coverage in the network is guaranteed by scheduling the sensors at the equal chance of being elected among the set covers, thus the minimal number of cover set formation was achieved. Target Coverage problem is grouped based on either Unique sensing range or multiple sensing ranges. The point of this study is to present a broad study of various researcher's approaches and their limitations for solving this efficient coverage with coverage problems in WSN.

A comprehensive survey is carried out based on the scheduling algorithms, set cover approach, in which we analyze different approaches and their complexity of the algorithms and techniques for optimal network coverage and connectivity. Firstly, the scheduling algorithm provides intermittently guaranteed efficiency for the necessary data service. This approach will effectively reduce the total number of active nodes in the network, thereby optimizing the network lifetime. Secondly, the set cover approach plays an important role in solving the problem of target coverage that group sensors in each cover set, thus achieving target coverage. Typical problems and open research challenges are discussed by classifying the literature strategies into three broad categories: adaptable coverage radius, coverage deployment strategy and sleep scheduling.

The rest of the paper is discussed as follows: Section 1 Introduction of target coverage in WSN has been discussed. In Section 2 gives a review of scheduling algorithms and set cover approach, target coverage with QoS constrain, limited by bandwidth, algorithms and its techniques. Section 3 gives typical research issues and open challenge problems. Section 4 includes a comparative analysis of target coverage and connectivity techniques and concluding observations in Section 5.

## 2. Related Works

### 2.1. Scheduling Algorithm

In general scheduling algorithms provides effective mechanisms to reinforce the lifetime of the network by scheduling the sensor either operating or sleep mode. The usage of scheduling algorithms helps to save energy between the nodes and thus, extends the lifetime of network while satisfying applications such as Agricultural Monitoring, Military application needs. Scheduling algorithms help the sensor's network to equalize the load, additionally, all the sensors have an equivalent opportunity to get elected. This ensures connected coverage of the monitored field.

Trust-based Probabilistic Coverage algorithm [1] intends to cover significant areas in energy adequate and reliable manner by alleviating the difficulties imported by built-in vulnerabilities related to sensor nodes and the monitored environment, by adopting a trust model. Integer Linear Programming (ILP) which guarantees the Quality of service against uncertainties are introduced either by a node or an environment.

An iterative estimation based on combinatorial relaxation [2] is done by optimizing the number of sensors organized in a region to establish coverage and connectivity. A novel hybrid genetic algorithm [3], which generate near-optimal solutions by dividing all nodes into a maximal number of disjoint set covers, thereby all set cover will be able to observe all targets in the network. These disjoint set covers are activated in sequence to cover an entire detecting area as well as by extending the network lifetime in a network.

An efficient learning automata-based scheduling algorithm [4] focused to prolong the lifetime of the network. Learning automata determine whether the node is a superfluous node or not and to schedule the sensor either too active or sleep state if the node is redundant it goes to sleep mode to save the energy for future purpose.

Energy-Efficient Connected Target Coverage Algorithm [5] is used to increase the lifetime as well as to minimize the energy utilization in the network. The Communication Weighted Greedy Cover algorithm is used as a Maximum cover tree problem to resolve a linked target coverage problem. A greedy technique is used to decide on the initial set to cover the communication cost of the targets. The Overlapped Target and Connected Coverage issue were proposed which shows that an equal quantity of energy was used while transmitting and receiving data from the sensor. In probabilistic coverage, a model was proposed for target detection applications whereas an estimation coverage model was proposed to estimate the data to detect at a specific area.

The two heuristic algorithms [6] were discussed which authenticate the information coverage model instead of simplistic disk coverage model. The connected cover formation (CCF), cover formation and relay placement with redundancy removal (CFRP-RR) algorithm to discover the estimated solutions for the sensor position problem which achieve both coverage and connectivity, where CCF perform better than CFRP-RR algorithm in sensor placement.

Target coverage based on probabilistic sensors elaborates [7], its objective is to minimize the network cost for target coverage using a genetic algorithm. The Minimum disclosure accuracy problem was defined, where the objective is to achieve minimum detection probability by prolonging the network lifetime for all targets in the network. The probabilistic model-based Connected Target Coverage (CTC) problem was studied in which each target was disclosed by at least one sensor above the predefined threshold, thereby reducing the CTC problem under the probabilistic model to 0/1 disk model.

The usage of nature-inspired design such as (artificial bee colony and particle swarm optimization) [8], highlights the scheduling and deployment of sensors for target coverage problems. The objective is to identify the optimal locations where the sensors are deployed based on the pre-specified sensing range by performing scheduling activities in a network.

The Nash Q-Learning node scheduling algorithm [9] for coverage and connectivity maintenance where each node learns its optimal action autonomously to enhance coverage rate and establish a communication link in a network. The author in [10] proposes a novel energy-efficient wireless sensor network coverage approach based on a genetic algorithm, to achieve the desired balance between target coverage and energy consumption. In particular, the purpose of this work is to cover the 2D sensing region by selecting a limited number of sensors.

## 2.2. Set cover approach

The set cover approach plays a major role in the target coverage and it is classified into disjoint and non-disjoint set cover. Dis-joint set cover refers to the target when it is enclosed by just a single sensor and when the intersection of the set is empty. Non-disjoint set cover refers to the sensors in the cover set that require not be disjoint [11].

A greedy approach based on Q-coverage maximum connected cover set [12] framed by scheduling the sensors based on Q-coverage and connectivity, to extend the network lifetime. It is classified into three phases based on the remaining energy of the sensors. In coverage phase which guarantees the order of coverage, if the requirement is satisfied the net cover set was defined. A breadth-first

search design is used to find the direct path from every node in the connected cover set to the sink. By removing the redundant sensors which led to minimizing connected cover set in the network. Priorities of sensors are updated based on the remaining energy of the sensors.

An adaptive scheduling design based on cellular learning automata [13] is highlighted to reduce the number of active nodes in the network. Thus, an accomplished scheduling algorithm based on learning automata that divide the sensor nodes into sets where energy was consumed by activating a minimum number of operating nodes and it maximizes the network lifetime.

High-Energy-First (HEF) was proposed [14], it prioritizes the sensors based on the leftover energy. Here the target coverage problem is focused based on the scheduling mechanisms and adjustable sensing ranges. HEF works based on the three phases, for example, the cover set was generated based on the higher residual energy such an extent that it covers at least one uncovered target and the ultimate aim is to minimize the cover set by removing sensors at a time which sensor was not covered.

The proposed greedy algorithm in [15] highlighted to produce together disjoint and non-disjoint set cover set based on the left out the energy of the sensors in each cover set, where scheduling mechanism was carried out in which an optimal number of sensors are selected to cover the integrated targets. Thus, the coverage constraint was satisfied in the network. But, the proposed algorithm avoids the cost efficiency, thus it satisfies the authors existing works drawback in which it selects the sensors based on cost.

Classical weighted greedy set cover which categorizes the sensors into a maximal number of cover sets that are organized either disjoint and non-disjoint cover set [16]. Sensors are activated in sequence based on round-robin mechanisms till all sensors are drained their energy. Thus, the network lifetime was extended by covering the entire targets.

The three centralized learning automata-based scheduling algorithms were projected to deal with the target coverage problem [17]. In algorithm 1, the activation time of the cover set is given during target monitoring phase, thereby coverage constrain was satisfied. In algorithm 2, the scheduling mechanism based learning automata was done for cover set formation. In algorithm 3 get terminated when the cover set with a minimal number of sensor nodes was reached.

An efficient scheduling algorithm in [18] was designed where the sensor nodes are arranged into various cover sets in which all the targets are monitored. In algorithm1, redundant nodes are removed therefore residual energy of sensors was restored until the entire target was observed.

In algorithm 2, the scheduling mechanism is performed to save residual energy. In algorithm 3, the action-set formation was done to maximize the network lifetime as well as cover set at all stages which examine all the targets in the network, algorithm 3 overcome the drawback of design 1 and 2.

Modified genetic algorithm in [19], focused to solve coverage problem by maximizing the network lifetime. Here the sensor is grouped into each cover set based on the activated sensors, where the fitness function of the Genetic algorithm was determined. Thus, the fitness function of each chromosome represents the disjoint cover set and coverage percentage of partial cover set based on the activated sensor in each cover set.

Greedy algorithm-based target scheduling uses a centralized method to solve Maximum Set Cover for Directional Sensor Networks (MSCD) [20], which is considered as NP-complete. Node wake-up scheduling protocol schedules the sensors either to active or sleep state to consume energy among the nodes. The proposed target scheduling mechanism uses the energy in an efficient way such that network lifetime is maximized by covering the entire targets.

The two polynomial-time algorithms namely, specific Adjustable Range Set Cover with Pushback (ARSC\_P) and Adjustable Range Set Cover with Selective pushback (ARSC\_SP) were projected in [21] to solve the target coverage problem. It has sensor nodes with adjustable sensing ranges to save energy by selecting the smaller sensing range over the larger area, thus, energy is saved by choosing the minimum number of cover set in a circular pattern.

Modified hill-climbing algorithm [22] defined which solve the Minimum Cover Set Problem, and to be proved as an NP-Hard problem called Vertex Cover Problem, Greedy Minimum set cover and linear polynomial rounding algorithm were proposed to solve Minimum Cover Set Problem.

Centralized target k-coverage and appropriated connected target k-coverage algorithm was projected in [23], where it satisfies the energy-efficient connectivity and coverage in HWSNs. The algorithm is designed in such a way that every target was secured by at least k-active sensors. Therefore, projected algorithms consider k-coverage with 1-connectivity by limiting the active sensor nodes, such that each cover set is connected to the base station.

In [24] OECCH (Optimized Energy-efficient Connected Coverage Heuristic Algorithm) builds the connected cover trees to enhance network lifetime with full coverage and to avoid premature convergence of connected coverage. In [25] how to optimize the coverage with network connectivity for industrial applications was presented. For instance, the authors in [26] proposed how to improve the

monitoring quality and guaranteeing target coverage with connectivity based on graph theory in EW-WSNs "Energy Harvesting Wireless Sensor Networks". In [27] addition to generating cover sets for targets observation, the proposed solution also provides a power-optimized shortest path from the sink to the sensor node and from set cover to sink, which keeps a record of the process of targets and sensor monitors the remaining energy to find a route that is power-optimized to maximize the lifetime of the sensor networks.

### 2.3. QoS constrain for Target coverage

In most of the applications, where data quality control concerning robustness and accuracy is essential, more than one sensor per time can cover all or some of the targets. The connected problem of k-coverage is dealt with in [28]. The authors have proposed centralized and distributed algorithms that select a limited number of sensors, thus providing connectivity and covering each point in a given query region with at most k discrete sensors.

The works of [29-31] tackle the issue of k-coverage where compatibility is guaranteed if the range's contact is at least twice that of sensing range. The author suggests an efficient centralized and decentralized algorithm but requires a networking scheme to use them in the target coverage problem. The authors tackle the issue of the k-target coverage problem in [32], thus taking network usability into account. They create an optional solution that is based on an effective LP formulation and a solving approximation algorithm. They too introduce a greedy low-cost heuristic algorithm that is useful for realistic implementation.

In coverage problem where there are specific coverage requirements for each sensor (Q-coverage issue) is explored in [33]. The authors use linear programming techniques to build a general optimization architecture that incorporates an upper-bound lifetime and a generation approach based on a column. However, their solution does not involve access to the network.

Additionally, the issue of k-coverage was presented from several aspects. A limited motion assisted k-coverage deployment issue is developed in [34], where the minimal collection of sensors is chosen and relocated to appropriate locations so that at least k sensors cover every point in the whole region. The problem of Directional k-coverage (DKC) in-camera fitted sensor networks is discussed in [35]. Due to the linearity of the sensing paradigm and the efficient sensing, the DKC concern is distinct from that addressed in conventional sensor networks.

A distributed k-coverage algorithm [36] is implemented which leaves a limited number of areas uncovered. The



paper of [37] discusses the issue of linked k-coverage in heterogeneous WSN, while the issue of k-coverage is studied in the presence of sensor mobility. In [38] this paper, we discuss the issue of network existence optimization when capturing certain varied QoS coverage constraints in these networks of surveillance sensors networks and proved that this issue belongs to class NP-complete. To integrate service quality (QoS) into the network and maintain consistent monitoring of the specified target range, the paper discusses the Q-Coverage issue which is one of the alternatives of the standard target coverage problem where the target is covered by at least Q-sensors in each cover range. A cover set is a subset of sensors, covering whole targets in a single iteration. A greedy heuristic-based strategy, i.e., maximum life-limit coverage, which restricts the uses of sensors which poorly cover targets and encourages full coverage and energy use of those sensors.

## 2.4. Target coverage limited by bandwidth

In application scenarios where significant volumes of information are required to be distributed and the sink time division protocol has a limited number of available time slots[39], a limited amount of bytes can be transmitted by the sensors in each cover package. In [40] the author poses the minimum breach problem, where the performance improves the number of channels and improves the number of sensors on the network coverage of the sensors is examined. The problem of target coverage under a bandwidth constraint is formulated as the least violation problem where the aim is to divide the sensors into sets of disjoint coverage while maintaining the highest possible number of targets in each cover. An extension of the previous work is formulated in [41]. Three instances of the issue are evaluated by the authors: minimum breach, minimum cumulative breach, and minimum individual breach time. The goal of the first scenario is to find a given number of covers sets when the cardinality within each cover set has to be lower than  $W+1$  and the overall violation has to be minimized.

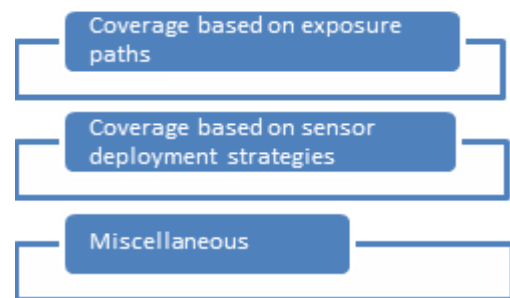
Two comparable instances of a coverage breach problem are presented in [42]. In the first scenario, the purpose is to improve the maximum amount of network lifetime by reducing the total breach time, whereas in the second, optimum breach rate value is allowed, while the lifetime must be maximized. They introduce an LP-based algorithm and a greedy heuristic to solve the problem of enabling the sensor nodes to become a member of many cover sets. Although the network connection is not considered in previous approaches, the work [43] incorporates a greedy heuristic that produces connected cover sets within constraint bandwidth. For 1-hop settings, the author equates their solution with the previous approaches. The results show that their approach has significantly fewer cover sets, but each cover set will track more goals than the other approaches.

## 2.5. Target Coverage and Connectivity Algorithms

**Static PoIs:** The basic concept of this PoI coverage Deployment Algorithm is given: all the sensors are initially within the radio range of the base station. Both sensors use a similar algorithm except the movement of every sensor node takes its own decision. The sensor moves to a predefined point that could be the PoI. We form horizontal lines between the sink and the PoI. The gap movable by the sensors is restricted to maintain connectivity. In [44] it suggests a distributed scheme, where nodes of the mobile sensors switch concentrically circular routes surrounding static PoIs. The purpose of the research is to make sure PoI coverage and its event are reported to the base station.

**Mobile PoIs:** The authors of [45] suggest three for mobile PoIs strategies for getting to the Mobile PoI: In the first approach, sensor nodes are returned to the base station before installing to the new location PoI. In the second approach, sensors continue to push straight ahead to the new PoI site, without returning to the base station. This technique shortens the time taken to accommodate the additional PoI but also lowers coverage quality as a required further sensor to maintain the connection. In the third approach, a sensor begins to move straight ahead line from the base station and PoI's new spot. This technique guarantees a higher quality coverage and reduces the time needed to cover PoI.

## 2.6. Techniques for optimal network coverage and connectivity



**Figure 1.** Techniques for optimal network coverage and connectivity.

Figure 1. represents the techniques used for optimal network coverage and connectivity

### 2.6.1 Coverage based on Exposure Paths

Strategies that use exposure paths to address the question of coverage in wireless sensor networks are essentially a

problem of combinatorial optimization. When designing the coverage problem, there are two types of viewpoints for optimization: worst-case and best-case coverage. The problem is usually solved in the worst-case scenario by attempting to find a path via the sensing field, such that an entity traveling through each path has the least accuracy of the nodes. The minimum exposure path [46] and the maximum path of breach [47-49] are two prominent ways of handling the worst-case. For the best-case coverage, on the other hand, the aim is to find a route that will have the best accuracy and therefore the object traveling along the path is most likely to be identified by the nodes. The maximum exposure path and maximum support path [50] are two solutions to addressing the best-case coverage problem.

### 2.6.2 Sensor deployment-based coverage strategies

The correct alternative to the coverage issue is to look for sensor implementation approaches that can optimize coverage but also as preserve a network graph that is linked globally. Many deployment approaches have been investigated to achieve an optimized architecture of the sensor network minimizes costs, offers high detection coverage and is immune to random node failures, etc. We describe briefly the following sensor deployment algorithm for static, mobile, and mixed sensor networks aimed at providing optimal field architecture for sensing, such as Imprecise Detection Algorithm (IDA) to minimize communication traffic and the number of sensors, Potential Field Algorithm(PFA) to maximize coverage with k-connectivity [51,52], Virtual Force Algorithm(VFA) to redeploy mobile nodes to maximize the coverage [53,54], Distributed Self-Spreading Algorithm (DSSA) to optimize coverage and preserve uniformity in the network[55], VEC, VOR and MiniMax Algorithm to reduce coverage holes [56], Bidding Protocol(BIDP) to reduce coverage holes and minimize the cost during re-deployment [57], Incremental Self-Deployment Algorithm(ISDA) for optimizing coverage[58,59], Integer Linear Programming Algorithm(ILPA) to maximizing grid coverage with an optimum number of sensors [60], Uncertainty-Aware Sensor Deployment Algorithm(UADA) for reducing the total number of sensors [61].

### 2.6.3 Miscellaneous Strategies

In this section we discuss that ensures both coverage and efficiency in a detection zone while simultaneously minimizing stability and increasing the overall life of the network. The area managed by the active node community is not lesser than the area that can be monitored across all node collections and access to the network is preserved until the redundant nodes are switched off.

## 3. Typical Issues and Open Research Challenges

Numerous scheduling algorithms and set cover approaches are performed to improve the target coverage and connectivity in WSNs. Yet there are few typical issues and open research challenges, specific to target coverage and connectivity issues for which more analysis is required. Table 1 summarizes the related work done under various approaches.

### 3.1. Significant Challenges in wireless sensor networks

The considerable issues in wireless sensor networks are network connectivity, coverage, sensing range, energy, lifetime, node deployment, node type, sensor relocation, obstacle adaptability, coverage holes, etc. Coverage plays a significant problem in WSN which is related to energy consumption, network reconfiguration, connectivity. How to achieve maximum coverage is an open research issue in wireless sensor network deployment. The sensor needs a battery for energy since it operates without human assistance. To increase the network lifetime energy is needed. To reducing energy and by maximizing the lifetime of the network is executed by using energy-efficient communication and routing techniques.

The node deployment is classified into two types a) Static Deployment b) Dynamic Deployment. In static deployment, based on the optimization strategy it chooses the best location and position of the sensor nodes won't change thought the network lifetime. Currently, static deployment consists of deterministic deployment and random deployment. Dynamic deployment is done by the deployment of the robot. To get the highest performance of the network, to begin the work, sensor nodes robotically move to the appropriate location. Node types are classified into two classes: the uniform sensor network and a diverse sensor network. In a uniform sensor network, every node in a network is identical and has an equal capability. In an interdependent sensor network, every node in a network is not identical and does not have an equal capability. Sensor relocation is defined by detecting the coverage hole the redundant nodes are displaced to the hole region. Sensor relocation takes place due to balancing energy consumption and message overhead.

The holes are classified into three types namely, coverage holes define a node area. Routing Holes are defined in a network where the available nodes can't take part in the authentic routing of the data due to battery exhaustion or due to faulty nodes. Jammer Holes are defined in an area, nodes able to sense the existence of the object but not capable to communicate reverse to the sink due to communication jamming.

### 3.2 Typical issues based on coverage and connectivity [62-77]

There are three classes of approaches to manage coverage and connectivity issues in WSNs namely, firstly, adaptable coverage radius which helps to adjust the transmitting and sensing range so that energy was saved among the sensor in a cover set, secondly, coverage deployment strategy helps to maintain the cover set by having an optimal number of sensors in the field, thirdly, for efficient coverage and energy consumption sleep scheduling mechanism was carried out among the sensors

#### 3.2.1 Adaptable Coverage Radius

In an existing network, detecting range of the sensor is considered as fixed, the guidelines of adaptive radius mechanism are reducing the covers, among the detecting range to keep up the Quality of service of coverage over a predefined finding stage. By adapting the communication or detecting area of sensor node power is saved.

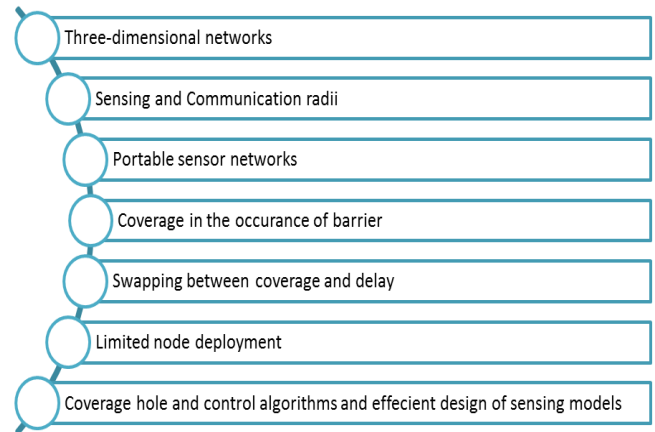
#### 3.2.2 Coverage deployment strategy

Coverage deployment strategy plays a significant part in energy conservation. One of the dependable challenges is to exploit the coverage and keeping up the deployment of sensors at a lower cost in the detecting field, especially when the observing area is unidentified and likely unsafe.

#### 3.2.3 Sleep Scheduling Mechanism

Sleep Scheduling Mechanisms are considered as the feasible approach for conserving energy surrounded by the nodes in the networks, while the remaining nodes remain dynamic to provide consistent service. The multiple energy-saving modes that can be given by a sensor are on-duty, sensing on-duty, transceiver on-duty, off duty. The end goal is done by making the operating nodes to keep up both sensing coverage and access to the network. As portrayed before, we outline the common coverage and network issues in WSN as presented in Table 1.

### 3.3 Open problem and research challenges [78-80]



**Figure 2.** Open problems and research challenges in WSNs

Various open problems and research challenges about WSNs are summarized as follows:

#### 3.3.1 Three-dimensional networks

An application, such as oceanographic information accumulation, contamination observing, and seaward explorations poses numerous challenges to the coverage and network issue. In three dimensions the thickness of nodes is relatively higher when compared to two-dimensional regions. Other than the coverage issue, sensors should have a capacity to relay the information to the sink using multi-hops; thus, it should facilitate their lowest point to ensure an associated network.

#### 3.3.2 Difference in sensing and communication radii

While modelling the sensing ranges in a circular pattern can prompt highly inaccurate outcomes. Similarly, the communication range of a sensor changes significantly due to multiple paths and surveillance impacts. Subsequently, the binary disk model of communication is excessively optimistic.

#### 3.3.3 Portable sensor networks

Several algorithms are intended to enhance the quality of coverage and connectivity of the networks. In any case, the better part of the algorithm concentrates only on the arbitrary movements of nodes rather than the portability models. From one viewpoint, mobility postures the challenge of ensuring coverage consistently.

### 3.3.4 Coverage in the occurrence of barrier

Coverage within the sight of hindrance is one of the demanding problems and has not been tended in the existing works. One of the existing research work discusses the presence of obstacles in the circular pattern in displaying the sensing range of the node and in an additional work if identified by discovering the most excellent coverage path in the existence of both opaque and transparent obstacles.

### 3.3.5 Swapping between coverage and delay

Based on sleep scheduling mechanisms and topology control approaches, sensor selection schemes are planned

are likewise pointed towards extending the lifetime of the networks. In topology control, nodes change their communication radii based on nearby statistical limitations to cut off the redundant connections which enhance the conflict and collisions.

### 3.3.6 Limited node deployment

In most sensor deployment mechanisms, it was considered as the best node deployment is a demanding issue that has already been verified to be NP-hard. To handle such complexity, a few heuristics algorithms have been projected to discover a suboptimal solution.

Table 1. Outline the common coverage and network issues in WSN

Classes	Approaches	Proposed	Deployment Strategy	Coverage Radius	Characteristic
Adaptable coverage radius	Computational sets	Adjustable Range-Set Covers	Random	Adjustable	Centralized energy-efficient
		Elitist non-dominated sorting genetic algorithm	Random	Adjustable	Distributed Cluster-based coverage control
		Coverage with uniform sensing	Random	Uniform and Adjustable	Adjustable sensing ranges based on energy efficiency
		Coverage with two adjustable Sensing range			
		Distributed algorithm using range adjustable sensors	Random	Uniform and Random	Distributed area coverage
Coverage deployment strategy	Computational geometry	Seamless Coverage	Deterministic	Fixed	Centralized energy-energy efficient
		Efficient geometric method where communication and sensing range is the same	Random	Distributed	Distributed Coverage hole detection time and energy consumption



		Geometry –based activity scheduling scheme	Random	Fixed	Preserving Target area Coverage
		VEC,VOR	Random	Any	Distributed
		CCP	Random	Fixed	Distributed
		OGDC	Random	Fixed	Distributed
	Virtual Forces	Virtual Force directed coverage optimization	Random Uniform	Any	Centralized energy consumption
		Virtual Force based node self deployment	Random	Any	Higher exposure rate and faster convergence time.
		Virtual Force	Random	Fixed	Distributed
		CPVF	Random	Fixed	Distributed
	Mobility	C3R,ECR	Random	Fixed	Hole Recovery
		VEC-based	Random	Fixed	Hole Recovery
Sleep Scheduling Mechanism	Disjoint sets	Dominating sets	Random	Fixed	Energy-efficient Centralized or distributed
		Hybrid genetic algorithm	Random	Any	Coverage-guaranteed algorithm to improve network lifetime
	Sleep Scheduling	Off-duty eligible rule	Random	Any	Distributed energy-efficient
		Coverage Maximization with Sleep Scheduling Protocol	Random	Fixed	Maximize sensing coverage
		A distributed heuristic range-	Random	Fixed	Distributed

		based sleep scheduling algorithm			
		LDCC	Random	Any	Distributed
		Partial Coverage Learning Automata	Random	Any	Partial Coverage

Table 2. Comparative analysis of Target Coverage Techniques[Scheduling Algorithms]

Approach Used	Coverage Type	Solved issues	Algorithm Complexity	Limitations
Trust-based Probabilistic Coverage Integer Linear Programming	Probabilistic Coverage	Coverage and Connectivity	$O(n \log n)$	Topology was not concentrated
Iterative approximation based on combinatorial relaxation	Area Coverage	Coverage and Connectivity	NP-Complete	Energy
Novel hybrid genetic algorithm	Target Coverage	Network Lifetime Coverage	NP-Complete	Energy
Efficient scheduling based on learning automata	Target Coverage	Network Lifetime	NP-Complete	Connectivity
Connected Target Coverage	Target Coverage	Sensing Coverage Network Connectivity	NP-Complete	Minimization of cover set
Connected Cover Formation algorithm  Cover Formation and relay placement with redundancy removal algorithm	Target Coverage	Coverage Connectivity	NP-Complete	Energy

Target coverage based on probabilistic sensors	Target Coverage	Network cost was minimized	NP-Hard	Topology was not concentrated while detection
Sensor Deployment and Scheduling for Target Coverage	Target Coverage	Network Lifetime	NP-Complete	Coverage

Table 3. Comparative analysis of Set cover approaches

Paper Highlights	Approach	Solved Issues	Algorithm Complexity
Q-Coverage maximum connected set cover	QC-MCSC based greedy approach	Network lifetime Coverage and Connectivity	-
Cellular learning automata	Adaptive scheduling for set cover problem	Energy consumption Network lifetime	NP-complete
High-Energy-First heuristic for energy efficiency target coverage	Centralized algorithm for energy efficiency in target coverage problem	Formation of minimal cover set Energy consumption	
Disjoint and Non-disjoint set cover	Greedy algorithm	Coverage	Log(m) O(dn <sup>2m</sup> )
Probabilistic coverage model	Classical weighted greedy set cover	Network lifetime	NP-complete
Learning automata (disjoint and non-disjoint cover set)	Centralized learning automata-based scheduling algorithm	Coverage Lifetime of the Network	
Solving the target coverage problem using cover set learning automata	Efficient scheduling algorithm	Network lifetime	
Disjoint set cover problem	Modified genetic algorithm	Network lifetime	NP-complete
Solve MSC for directional sensor network	Greedy algorithm based target scheduling approach	Energy consumption Network lifetime	NP-complete

Energy-Efficient method with adjustable sensing ranges	Adjustable Range set cover with push back and selective pushback approach	Energy Consumption Coverage	
Minimum set cover problem	Modified hill-climbing algorithm Greedy algorithm	Formation of minimum set cover	NP-hard
On connected target k-coverage in heterogeneous WSN	Centralized and Distributed target k-coverage algorithm	Energy consumption Connectivity Coverage	NP-complete
Target Coverage in random WSNS	Disjoint and Non-disjoint Connected Coverage Algorithm	Energy consumption Connectivity Coverage	NP-complete

**3.3.7 Initiate and improve coverage control algorithms**

Coverage control algorithms are to be designed once the network was framed, and these algorithms run throughout the lifetime of WSNs. Yet, all these algorithms are considered as NP-hard problems when related to optimal node deployment, which ultimately provides the best optimal arrangement in the network.

**3.3.8 Coverage hole identification and repair system:**

Even though the target coverage and network communication issues have been discussed in several ways in the current literature works, however, several other research works were centered on coverage holes. The two important challenges are how to identify the holes and how to repair the holes, these may occur due to the random arrangement and energy weariness in the network.

**3.3.9 Efficient design of sensing models:**

Since most of the present mechanisms on coverage and network connectivity concerns are established on either disc or probabilistic detecting model. Based on the exiting research works, it was identified that the detecting range

can be affected by environmental conditions and blocking across the network.

**4. Comparative Study on Target Coverage based on scheduling algorithms and set cover approaches**

Now we compare various approaches, issues handled, and algorithm complexity based on the related works [1-8]. The comparison table is given in Table-2 and Table-3 summarizes related work done under set cover approaches [11-23,27]. In this division, we have made the comparative analysis of scheduling algorithms based on the three coverage types namely, probabilistic coverage, area coverage and target coverage based on the assessment done by the authors in their existing works. Our analysis is based on the type of coverage, issues handled; algorithm complexity and its limitations are discussed in Table 2 and Table 3 summarize, the analysis based on the target coverage problem using set covers, issues handled and their algorithm complexity which is examined in their respective papers. Based on the above comparison study we conclude that to maintain coverage with connectivity, parameters such as energy, sensing and communication range, network lifetime must be satisfied.



## 5. Concluding Remarks

Target Coverage and Network connectivity are the two fundamental problems that greatly affect the QoS of WSNs. Initially, a brief introduction of target coverage and connectivity was given in this survey. Secondly, we take scheduling algorithms and set cover approaches into consideration and followed by the summary of research issues and challenges in WSNs are focused. Thirdly, an issue based on coverage as well as connectivity is taken based on three aspects to manage coverage and connectivity issues. This review guarantees the connected coverage for the entire observed field and load balancing among the sensors in each cover set, thereby achieving the QoS in the network. Finally, a comparative analysis was done based on the coverage type, issues handled and the algorithm complexity. Future work will focus on improving the coverage with reliable connectivity to minimize the cover sets by proper scheduling of sensors in each cover set and to reduce computational time to provide a near-optimal solution.

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## References

- [1] Zahra Taghikhai, Nirvana Meretnia, Paul J.M. : A Trust-based Probabilistic Coverage Algorithm for Wireless Sensor Networks. *Procedia Comput. Sci.* 21, pp.455-464 (2013).
- [2] Mahmud Mansour, Fethi Jarry. : An Iterative solution for the coverage and connectivity problem in Wireless Sensor Network. The Seventh International Symposium on Applications of Ad hoc and Sensor Networks. *Procedia Comput. Sci.* 63, pp. 494-498(2015).
- [3] Chia Pang Chen, Cheng Long Chuang, Tzu Shiang Lin, Chia-Yen Lee, Joe Air Jiang. : A Coverage guaranteed algorithm to Improve Network Lifetime of Wireless Sensor Networks. *Procedia Eng.* 5,pp.192-195(2010).
- [4] Habib Mostafeai, Mohammad Reza Meybodi.: Maximizing Lifetime of Target Coverage in Wireless Sensor Networks using Learning Automata. *Wireless Pers Commun.*71, pp.1461-1477 (2013).
- [5] Qun Zhao, M.Gurusamy.: Maximizing Network Lifetime for Connected Target Coverage in Wireless Sensor Networks. *IEEE Int. Conv. Wireless and Mobile Computing, Networking and Communicataions,* (2006), DOI: 10.1109/WIMOB.2006.1696380.
- [6] Huping Xu, Jiajun Zhu, Bang Wang.: On the deployment of a Connected Sensor Network for Confidential Information Coverage. *Sensors,* 15(5), pp.11277-11294 (2015).
- [7] Anxing Shan, Xianghau Xu, Zongmao Cheng.: Target Coverage in Wireless Sensor Networks with Probabilistic Sensors, *Sensors* 16(9), 2016.
- [8] S.Mini, Siba K.Udgata, Samrat L.Sabat.: Sensor Deployment and Scheduling for Target Coverage Problem in Wireless Sensor Networks. *IEEE Sens J,*14, pp.636-644 (2014).
- [9] Anamika Sharma & Siddhartha Chauhan.: A distributed reinforcement learning-based sensor node scheduling algorithm for coverage and connectivity maintenance in a wireless sensor network. *Wirel Netw,* 26, pp.4411-4429(2020).
- [10] Yang Chen, Xiaoguang Xu and Yong Wang.: Wireless sensor network energy-efficient coverage methods based on intelligent optimization algorithm. *AIMS,* 12(4&5),pp.887-900(2019), doi:10.3934/dcdss.2019059.
- [11] R.Deepa, Revathi Venkataraman, M.Pushpalatha and P.T.Ravichandran.: A Review on Cover Set Problem in Wireless Sensor Networks. *Jour of Adv Research in Dynamical and Control System,* 9,pp.151-161(2017).
- [12] Sunita Gupta, Dr K.C Roy.: Q-Coverage Maximum Connected Set Cover Heuristic for Connected Target Problem in Wireless Sensor Networks. *GJCST- E: Network, Web & Security,* 15(2015).
- [13] Reza Ghaderi, Mehdi Esnaashari, Mohammad Reza, Meybodi.: An adaptive scheduling algorithm for set cover problem in wireless sensor networks: A Cellular Learning Automata Approach. *Int. J. Mach. Learn. Comput.*2,pp.626-632(2012), doi: 10.7763/IJMLC.2012.V2.203.
- [14] Manju and Arun K. Pujari: High-Energy-First(HEF) Heuristic for Energy-Efficient Target Coverage Problem. *Int J AD HOC UBIQ CO.* 2,pp.45-58,(2011), doi: 10.5121/ijasuc.2011.2015.
- [15] Babacar Diop, Dame Diongue, Ousmane Thiare: Managing Target coverage lifetime in wireless sensor networks with Greedy set cover. *International Conference; MulGraB 2014*,pp.17-20 (2014), doi: 10.1109/MulGraB.2014.11.
- [16] Babacar Diop, Dame Diongue, Ousmane Thiare.: Target Coverage Management in Wireless sensor Networks. pp.25-30, *IEEE(2014).*
- [17] Hosein Mohamadi, Abdul Samad Ismail, Sharharuddin Salleh, Ali Nodhei.: Learning automata-based algorithms for finding cover sets in wireless sensor networks. *J Supercomputer,* Springer Science. pp.1533-1552 (2013).
- [18] Hosein Mohamadi, Abdul Samad Ismail, Sharharuddin Salleh.: Solving Target Coverage Problem Using Cover sets in Wireless Sensor Networks based on Learning Automata. *Wireless Pers Commun,* Springer Science, pp.447-463(2014).
- [19] Bibhudatta Sahoo, Veena Ravu, Punyaban Patel.: Observation on using Genetic algorithm for extending the lifetime of wireless sensor networks. *2<sup>nd</sup> National Conference-Computing communication and Sensor Network*,pp.9-13(2011).
- [20] Youn Hee Han, Chan Myung Kim and Joon Min Gil.: A Greedy Algorithm for Target Coverage Scheduling in Directional Sensor Networks. *JoWUA.* 1, pp.96-106.

- [21] Safwat Ali Khan, Zinat Ara and Mosarrat Jahan.: Energy-Efficient Methods to Maximize Network Lifetime in Wireless Sensor Networks with Adjustable Sensing Ranges. *Int. j. comput.* 03, 04,pp.743-749(2014).
- [22] Fatema Akhter.: A Heuristic Approach for Minimum Set Cover Problem. *IJARAI*. 4,6,pp.40-45(2015).
- [23] Jiguo Yu, Ying Chen, Liran Ma, Baogui Huang, Xiuzhen Cheng.: On Connected Target k-Coverage in Heterogeneous Wireless Sensor Networks. *Sensors* 2016, 16(1),doi: 10.3390/s16010104.
- [24] Danyang Qin, Jingya Ma, Yan Zhang, Pan Feng, Ping Ji and Teklu Merhawit Berhane.: Study on Connected Target Coverage Algorithm for Wireless Sensor Network. *Special Section on Mission Critical Sensors and Sensor Networks*. pp.69415-69425(2018).
- [25] G.J.Han, L.Liu, J.Jiang, L.Shu and G.Hancke.: Analysis of energy-efficient connected target coverage algorithm for industrial wireless networks.*IEEE Trans. Ind. Informat.*,13,1(2017).
- [26] Xuecai Bao, Longzhe Han, Xun He, Wenquen Tan and Tanghui Fan.: Optimizing Maximum Monitoring Frequency and Guaranteeing Target Coverage and Connectivity in Energy Harvesting Wireless Sensor Networks. *Mob. Inf. Syst.* (2019).Article ID 6312589, <https://doi.org/10.1155/2019/6312589>.
- [27] A. Katti.: Target Coverage in random wireless sensor networks using cover sets. *J.King Saud University., Comp.& Info. Sci.* <https://doi.org/10.1016/j.jksuci.2019.05.006>.
- [28] Zhou Z, Das S and Gupta H.: Connected k-coverage problem in sensor networks. In *Proceedings of the International Conference on Computer Communications and Networks*. pp.373-378.
- [29] Hefeeda M and Bagheri M.: Efficient k-coverage algorithms for wireless sensor networks, Technical report, School of Computing Science, Simon Fraser University.
- [30] Simon G, Molnar M, Gonczy L and Cousin.: Dependable k-coverage algorithms for sensor networks.*IMTC* pp.1-6 (2007).
- [31] Vu. C,Gao S, Deshmukh W and Li, Y.: Distributed energy-efficient scheduling approach for k-coverage in wireless sensor networks. *MILCOM* pp.1-7(2006).
- [32] Zhao Q and Gurusamy M. Connected k-target coverage problem in wireless sensor networks with different observation scenarios. *Comput. Netw.* 52(11):pp.2205-2220.
- [33] Gu Y, Ji Y, Li J and Zhao B.: QoS-aware target coverage in wireless sensor networks.*Wirel. Commun. Mob.Comput.* 9(12):pp.1645-1659.
- [34] Shen W. & Wu Q.: Minimum sensor relocation for k-coverage in wireless sensor networks. *CMC*.3(274-278).
- [35] Liu L, Ma H and Zhang X.: On directional k-coverage analysis of randomly deployed camera sensor networks, *ICC 08*. pp.2707-2711.
- [36] Kim H, Kim E.J & Yum K.H.Roal.: A randomly ordered activation and layering protocol for ensuring k-coverage in wireless sensor networks. *Third International Conference on Wireless and Mobile Communications*,2007.
- [37] Ammari H and Giudici J.: On the connected k-coverage problem in heterogeneous sensor nets: The curse of randomness and heterogeneity. *29<sup>th</sup> IEEE ICDCS*.pp.265-272.
- [38] Yu Gu, Yusheng Ji, Jie Li and Baohua Zhao.: QoS-aware target coverage in wireless sensor networks. *WIREL COMMUN MOB COM* 9(12):pp.1645-1659.
- [39] D Zorbas, C.Douligeris.: Power Efficient Target Coverage in Wireless Sensor Networks.*InTech,Sustainable Wireless Sensor Network*(2010).
- [40] Cheng M. X, Ruan L & Wu.W. : Achieving minimum coverage breach under bandwidth constraints in wireless sensor networks. *Proc.of INFOCOM 05*,pp.2638-2645.
- [41] Cheng. M, Ruan L & Wu.W. : Coverage breach problems in bandwidth-constrained sensor networks, *ACM Trans.Sen.Netw.* 3(2):12.
- [42] Wang. C,Thai M, Li Y. Wang F & Wu.W.: Minimum coverage breach and maximum network lifetime in wireless sensor networks. *Proc. Of GLOBECOM 07*, pp.1118-1123.
- [43] Zorbas.D & Douligeris.C. : Satisfying coverage and connectivity in bandwidth-constrained sensor networks.*ISCIT 2009*,pp.390-395.
- [44] M.Erdelj, E.Natalizio and T. Razafindralambo. : Multiple Point of Interest Discovery and Coverage with Mobile Wireless Sensors.*ICNC*(2012).
- [45] M.Erdelj,T.Razafindralambo and D.Simplot Ryl. : Covering Points of Interest with Mobile Sensors. *IEEE Transaction on Parallel and Distributed Systems*(2013).pp.32-43.
- [46] S.Megerian, F. Koushanfar, G.Qu, G.Veltri and M.Potkonjak.: Exposure in wireless sensor networks: Theory and Practical solutions. *WIREL NETW* 8(5):pp.443-454(2002).
- [47] X.Y.Li, P.J.Wan, and O.Frieder.: Coverage in wireless ad-hoc sensor networks. *IEEE Trans.Comput.* 52:pp.753-763(2003).
- [48] S.Meguerdichian, F.Koushanfar, M.Potkonjak, and M.Srivastava.: Coverage problems in wireless ad-hoc sensor networks. *InfoCom'01*(2001),pp.115-121.
- [49] G.Veltri,Q.Huang, G.Qu, and M.Potkonjak.: Minimal and maximal exposure path algorithms for wireless embedded sensor networks.*SenSys'03*, (2003),pp.40-50.
- [50] S.S.Dhilon,K.Chakrabarty, and S.S.Iyengar.: Sensor placement for grid coverage under imprecise detections.*FUSION'02*,(2002),pp.1-10.
- [51] O. Khatib.: Real-time obstacle avoidance for manipulators and mobile robots. *Int.J.Robotics Res.* 5(1):pp.90-98(1986).
- [52] S.Poduri and G.S.Sukhatme.: Constrained coverage in mobile sensor networks.*ICRA'04*, pp.40-50(2004).

- [53] Y. Zou and K.Chakrabarty.: Sensor deployment, and target localization based on virtual forces. *InfoCom'03*, pp.1293-1303(2003).
- [54] Y. Zou and K.Chakrabarty.: Sensor deployment and target localization in distributed sensor networks. *Trans.IEEE Embedded Comput. Syst.* 3(1):pp.61-91(2004).
- [55] N.Ho and P.K. Varshney.: A distributed self-spreading algorithm for mobile wireless sensor networks. *WCNC'03*, pp.1597-1602(2003).
- [56] G. Wang, G. Cao, and T. LaPorta.: Movement-assisted sensor deployment. *InfoCom'04* pp.80-91,(2004),.
- [57] G. Wang, G.Cao, and T. Laporta.: A bidding protocol for deploying mobile sensors, *ICNP'03*, pp. 80-91,(2003).
- [58] A.Howard, M.J.Matari, and G.S. Sukhatme.: An incremental self-deployment algorithm for mobile sensor networks. *Autonomous Robots special issue on intelligent embedded systems* 13(2):pp.113-126(2002).
- [59] A. Howard and M.J.Mataric.: A self-deployment algorithm for mobile sensor networks, *ICRA'02*(2002), pp.80-91.
- [60] K.Chakrabarty, S.S.Iyengar, H. Qi, and E.Cho.: Grid coverage for surveillance and target address in distributed sensor networks. *IEEE Trans. Comput.* 51(12):pp.1448-1453(2002).
- [61] Y. Zou and K.Chakrabarty.: Uncertainty-aware sensor deployment algorithms for surveillance applications. *GLOBECOM'03*( 2003).
- [62] M.Cardei, Jie Wu, Mingming Lu, M.O.Pervaiz.: Maximum network lifetime in wireless sensor networks with adjustable sensing ranges. *IEEE WIMOB* (2005). DOI: 10.1101/WIMOB.2005.1512935.
- [63] Jie Jia, Jian Chen, Gurian Chang, Yingyou Wen, Jingping Song.: Multi-objective optimization for coverage control in wireless sensor network with adjustable sensing radius. *COMPUT MATH APPL.* 57,11-12,1767-1775(2009).
- [64] Vyacheslav Zalyubovskiy, Adil Erzin, Sergey Astrakov, Hyunseung Choo.: Energy-efficient Area Coverage by Sensors with Adjustable Ranges. 2009, DOI:10.3390/s90402446.
- [65] Yipeng Qu, Starvrous V.Georgakopoulous.: A Distributed area coverage algorithm for maintenance of randomly distributed sensors with adjustable sensing range. *GLOBECOM* 2013). DOI:10.1109/GLOCOM 2013.6831085.
- [66] Hwa-Chun Ma, Prasan Kumar Sahoo, Yen-Wen Chen.: Computational Geometry based distributed coverage hole detection protocol for the wireless sensor networks. *J NETW COMPUTAPPL.* - <https://doi.org/10.1016/j.jnca.2011.06.007>.
- [67] San-Yuan Wang, Kuei-ping Shih, Yen-Da Chen, Hsin-Hui Ku.: Preserving Target Area Coverage in Wireless Sensor Networks by using Computational Geometry. *WCNC IEEE* 2010. DOI:10.1109/WCNC.2010.5506575.
- [68] Wang G, Cao, T, La Porta.: Movement-assisted sensor deployment. 4, pp.2469-2479 , *INFOCOM* 2004.
- [69] Zhang JHH.: Maintaining sensing coverage and connectivity in large sensor networks. Technical report UIUCDS-R 2003.
- [70] Chang and Wang.: Self-deployment by density control in sensor networks. *IEEE T VEH TECHNOL*, 57(3), 2008, pp:1745-1755.
- [71] Qin Xu, Jianping Wang.: Coverage optimization Deployment Based on Virtual Force-Directed in Wireless Sensor Networks. *IPCSIT* 2012. DOI:10.7763/IPCSIT.2012.
- [72] Xiangyu Yu, Weipeng Huang , Junjian Lan, Xia Qian.: A Novel Virtual Force Approach for Node Deployment in Wireless Sensor Network. *IEEE DCOSS*(2012). DOI: 10.1109/DCOSS.2012.32.
- [73] Chia-pang Chen, Cheng-Long Chuang, Tzu-shiang Lin, Chia-Yen Lee, Joe-Air Jiang.: A Coverage-guaranteed Algorithm to improve Network Lifetime of Wireless Sensor Networks. *Procedia Eng*, pp. 5-8, 2010.
- [74] Chanrit Danratchadacom, Chotipat Pornavalai.: Coverage Maximization with sleep scheduling for wireless sensor networks. *ECTIC* 2015. DOI:10.1109/ECTICon.2015.7207001.
- [75] Xueyan Li, Hongbin Chen, Feng Zhao, Xiaohuan Li.: A range-based sleep scheduling algorithm for desired area coverage in solar-powered wireless sensor networks. *WCSP* (2014). DOI:10.1109/WCSP 2014.6992026
- [76] Habib Mostafeai, Antonio Montieri, Valerio Persico, Antonio Pescape.: A Sleep scheduling approach based on learning automata for WSN partial coverage. *J NETW COMPUT APPL.* 80, 2017. pp 67-78. <https://doi.org/10.1016/j.jnca.2016.12.022>.
- [77] Chuan Zhu, Chunlin Zheng, Lei Shu, Guangjie Han.: A survey on coverage and connectivity issues in wireless sensor networks, *Journal of Network and Computer Applications.* 35,2, 2012, pp:619-632. [doi.org/10.1016/j.jnca.2011.11.016](https://doi.org/10.1016/j.jnca.2011.11.016).
- [78] Amitabha Ghosh, Sajal K.Das, Coverage and Connectivity Issues in Wireless Sensor Networks, Wiley Online Library, 2006.
- [79] Amitabha Ghosh, Sajal K.Das, Coverage and Connectivity issues in wireless sensor networks: A Survey. *PERVASIVE MOB COMPUT* 4 (2008), pp: 303-334.
- [80] W.Choi, S.K.Das, A novel framework for energy conserving data gathering in wireless sensor networks. *IEEE INFOCOM* 2005, pp: 1985-1996.