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A Comprehensive Survey of Coverage Problem and Efficient Sensor Deployment Strategies in Wireless Sensor Networks

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Abstract

Objectives: To study various aspects of coverage problem and various efficient sensor deployment strategies in wireless sensors networks. **Methods:** In this paper we have described various coverage related issues and how an efficient deployment strategy can improve the coverage depending on the application area of interest. **Findings:** Coverage and Connectivity are the two critical performance metrics of a Wireless Sensor Network (WSNs) which determines the Quality of Surveillance (QoS) provided by the network. Efficient deployment of sensors is one of the fundamental issues which can improve the coverage and reduces the coverage holes of the region of interest. The objective of optimal sensor deployment is to have at least one sensor such that each point of the beleaguered region is under the observable area of any of the sensor nodes. The coverage schemes based on Voronoi diagram, Delaunay triangulation and various other schemes has been elaborated. There are many unmapped issues related to coverage problem and sensors deployment that need to be explored and studied as an open research area. **Improvement:** This paper presents a broad overview of the different deployment strategies and various coverage problems in wireless sensor networks. We tried to create a clear platform for the neophyte researchers so that they could have an extensive idea about the relevant field of research in wireless sensor networks.

Keywords: Coverage, Deployment Strategies, Sensing Model, Wireless Sensor Networks

1. Introduction

Wireless Sensor Networks (WSNs) generally comprises of large number of tiny sensor nodes, having sensing capabilities, abilities to process and communicate data to other sensor nodes[1]. WSNs has a wide variety of applications from smart home to area monitoring, military application, tracking or environment monitoring, agriculture purpose and rainfall measure which is also extended to civil applications and education areas[2,3]. The coverage performance of a WSN network strongly depends on how efficiently the sensors are deployed such that the desired level of covered is obtained whereas power management, and routing protocol also have major impact on the coverage. Connectivity is another critical issue for design consideration of a sensor network for proper functioning of the network regardless of various diverse situations.

The coverage problem in Mobile Wireless Sensor Networks (MSNs) is an emerging field of research which is similar to dynamic coverage where the emergence of coverage hole is unavoidable due to various reasons. The mobile nature of the sensor nodes are well exploited in

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MSNs to enhance the overall network performance and reduces the redundancy in sensor deployment and as a result reduction in network cost.

In hostile environments where human intervention is too dangerous a well-organized deployment of sensor nodes will lessen the coverage holes and also enhances the connectivity and coverage of the area of interest[4,5]. Deployment of sensor nodes in a well-planned manner in beleaguered environment is always not feasible in real time scenarios, such as in the battlefields and deep inside the forests[6] where sensors are sprinkled from helicopter or aircraft. In case of deterministic deployment, lesser number of nodes are required as the deployment scenario is predefined, whereas contrary to that is random deployment. The performance of the network cannot be calculated until and unless the sensor nodes are fully deployed in the sensor networks[7–11]. Deployment of sensor nodes are mainly classified into two categories: Deterministic and random. The deployment strategy is chosen based on the area to be monitored and to attain maximum coverage[12–16].

Sensor networks are broadly classified into two types: Homogenous and heterogeneous sensor networks. In homogenous networks, sensors consist of same sensory range, communication abilities and same battery energy. Contrary to that heterogeneous networks may have either same or different sensor sensory range and communication range. The authors have discussed the connectivity and coverage issues in grid sensor networks and also derived mathematical expressions for the same[17]. The authors have proposed a new algorithm to deploy sensor nodes at the empty circles vertices in virtual grid sensor networks by the mobile robots which efficiently enhances the existing carrier based sensors deployment to achieve a desired sensing coverage[18]. There have been several algorithms proposed for coverage hole detection and intruder detection in sensor networks.

A novel algorithm EECDC (Energy Efficient Coverage Aware Data Collection) is proposed for energy efficient head node selection using the concept of Maximal Independent Set (MIS)[19]. The proposed algorithm ensures energy efficient coverage and increased network lifetime. LBER (Location Based Energy-Aware Routing) protocol is been proposed for easy discovery of neighbor nodes for efficient data routing and transmission[20]. This protocol consumes less amount of energy for route discovery and network activities, which further increases the network lifetime.

The authors have proposed a self-healing algorithm using Fuzzy Logic System (FLS) for exact positioning of the randomly deployed mobile sensor nodes[21]. This algorithm considers the Euclidean distance between the sensors for uniform distribution to ensure effective coverage and coverage redundancy and also consumes less energy in comparison to other existing schemes. The authors have investigated the impact of deterministic deployment of heterogeneous sensor nodes with two different sensing radii on coverage efficiency. The sensing cost is also significantly reduced as compared to homogeneous sensor network. They have also derived the relationship between the sensing radii necessary for providing complete coverage to a ROI[22].

The remainder of this paper is organized as follows. In Section 2, we present a brief overview of coverage and connectivity, an important parameter for measurement of quality of service in WSNs. In Section 3, we briefly highlight the deterministic and probabilistic sensing models used for WSNs. In Section 4, the coverage problems in WSNs are classified. In Section 5, we analyzed and studied the different coverage strategies. The various sensors deployment strategies are briefly discussed in Section 6. In Section 7, we concluded the paper with the existing methods which need to be significantly prolonged to encounter these challenges with an open research areas.

2. Important Aspects of Coverage and Connectivity in WSNs

2.1 Coverage

Coverage is regarded as one of the critical issues in wireless sensor networks. There are many definition of coverage in literature; the best of which describes that how efficiently the sensors are deployed in such a way that each and every part of the region of interest is covered. The coverage for static sensor network varies from that of dynamic sensor networks, which also depend on the various parameters such as mobility of the sensor nodes in order to improve the sensing coverage and intruder detection in different beleaguered scenarios.

2.2 Connectivity

Connectivity is another critical issue needs to be considered for proper function of the overall network. The network has to ensure that nodes can communicate with each other uninterruptedly. To maintain a highly connected network a necessary condition is $R_c > R_s$, where R_c and R_s are the communication and sensing range of a node respectively. Coverage and connectivity together can be considered as the performance metric to measure how efficiently the sensor network is functioning.

3. Sensing Model

In the literature survey, we have come across the two categories of sensing models: the deterministic sensing model and probabilistic sensing models which are further classified into Boolean or Disk sensing model, Shadow-fading sensing model and Elfes sensing model. These sensing models are described in[23].

3.1 Disk Sensing Model

In this model, a sensor sensory range is usually a circle or nice disk shaped which have a radius '*r*' and for generality the sensor is considered to be located at the center of the circle. The probability of detecting an event is '1' when the occurrence of an event is within the sensing coverage of the node and '0' in the contrary case. The event detection probability of a disk sensing model can be defined as

$$P(x) = \begin{cases} 1 & : 0 \le x \le r \\ 0 & : x > r \end{cases} \tag{1}$$

3.2 Probabilistic Sensing Model

- The Shadow fading sensing model hereby considers the shadowing effect owing to the presences of various obstacles in the propagation path. This is one of the most popular sensing models which are widely being studied, whereas the sensors' sensory range is not omnidirectional.
- The Elfes sensing model[24] is expressed as

$$C_{(x,y)}(S_i) = \begin{cases} 0 & : if \quad R_s + R_u \le d\ (s_i, p) \\ e^{-\omega a^{\beta}} & : if \quad R_s - R_u \le d\ (s_i, p) < R_s + R_u \\ 1 & : if \quad R_s - R_u \ge d\ (s_i, p) \end{cases} \tag{2}$$

where R_s is defined as the radius of the circle or disk and the probability to detect an object '*p*' for an interval (R_s-R_u, R_s+R_s), such that $a = d\ (S_i, p)–(R_s\text{-}R_u)$, ω and β are measured parameter for the detection of probability so that object is well within distance from the sensor node.

4. Main Categories of Coverage Problem in WSNs

A more through survey of coverage problem in sensors networks that emerges for providing a desired coverage is broadly classified into three categories i.e., blanket coverage, barrier coverage and sweep coverage.

4.1 Blanket Coverage

These types of coverage come into the picture when it is required to attain a static organization of sensor node that enhances the recognition of a target event in the field of interest.

4.2 Barrier Coverage

It is generally used to minimize the coverage holes and ensures intruder detection such that complete coverage is achieved in the sensing region and also to achieve efficient deployment of sensor nodes.

4.3 Sweep Coverage

It is one of the recent research areas, where sensors node are deployed and move across the sensing field or region of interest. Also there is tradeoff between the occurrence rate of event and to minimize the undetected portion or coverage holes in the region of interest. Figure 1 shows the classification of coverage problem.

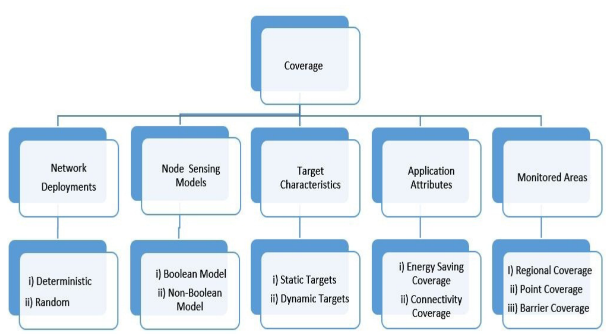

Figure 1. Classification of coverage problem.

In this literature survey, we aim to provide a comprehensive study and classification of coverage problem and comparison between the existing schemes.

5. Coverage Strategies

Coverage strategies which are centered on the backbone of acquaintance and potential fields, to application specific coverage to dynamic mobile sensors networks and duty cycle scheduling. The computational geometry arrangement is studied to obtain the maximum coverage in the field of interest[25]. The most commonly accepted structures of computational geometry are Voronoi Diagram and Delaunay Triangulation.

5.1 Voronoi Diagram

Let P = $\{p_1, p_2,.., p_n\}$is a set of discrete points which divides the two-dimensional plane such that all the points in subdivided regions are adjacent to the corresponding point than to any other point. These set of points in *P* are called generators, that partitioned regions is considered as Voronoi cells. Two points are adjacent if they share a common edge. Let consider two points *x* and *p* with Euclidian distance function $d(x,p)$. The Voronoi cell V_i with *I* be an index set and consider $(P_i) \in I$, then the Voronoi region can be expressed as:

$$V_i = \{x \in X \mid d(x, p_i) \le d(x, p_j) \; for \; all \; j \ne i\} \quad (3)$$

The Voronoi diagram is shown in Figure 2 of ten partitions whereas it is generally used for deploying sensors in random partitions, it can be generated by MATLAB, Network Simulator (NS2), and Mathematica software.

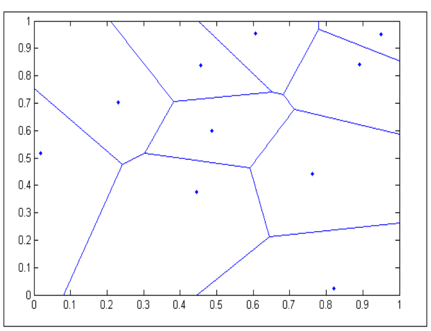

Figure 2. Voronoi diagram.

5.2 Delaunay Triangulation

A Delaunay triangulation is basically a triangulation DT(P) such that no points in set *P* are within the circum-hyper-sphere of any simplex in DT(P). It is well-known, Delaunay triangulation for *P* if *P* is a set of points there exist a unique triangulation. The Delaunay triangulation is shown in Figure 3.

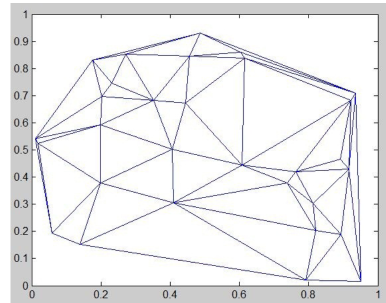

Figure 3. Delaunay triangulation.

6. Deployment Strategies of Sensor Nodes in WSNs

- The authors have stated Potential-field-based approach for sensors placement such that to maximize the coverage area[26–31].
- In Wireless sensors networks, there are many existing algorithms to improve energy efficiency, network lifetime and minimizing the coverage hole and protocols to compute the target locations of each sensor[19–21,32].
- Generally there are three protocols which are normally used to plot the sensors in the sparse networks are VEC (VECtor-based), VOR (VORonoi-based) and Minimax.
- Deterministic deployment of sensors is basically applied for static scenarios where the location of sensors is already predefined. Contrary to that random deployment is used for real time applications or scenarios where the location of sensors is not known well in advance.

7. Open Research Issues and Conclusion

In the literature review, we have come across many hot topics of research based on our critical investigation on these issues in WSNs. Here are some of emerging field of research listed below:

- Most of the works in coverage is done for static networks whereas still lot of research is yet to be done in dynamic coverage and intruder detection in mobile sensors networks. It can be extended to 3D dynamic search for coverage in wireless sensors networks[33].

- Deployment of sensors such that it attains maximum coverage in real time application and connectivity also sustained even in a harsh surrounding environment. To increase network lifetime through sensor scheduling and also maintain *k*-Coverage and *k*-Connectivity whereas tradeoff between delay and coverage can also be seen[34].
- A collaborative approach for occurrence of event in hybrid sensors networks, which consists of homogenous and heterogeneous sensors nodes which are used to enhance area coverage and adaptability to avoid obstacle are the hot topics and emerging field of research.

In this paper, we have investigated and reviewed the different deployment strategies and various coverage problems in wireless sensor networks. We tried to give a brief overview to neophyte researchers, based on that they can have an idea about the relevant field of research in wireless sensor networks.

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