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A Survey of Sensor Deployment Schemes in Wireless Sensor Network

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Abstract: WSN is a group of low-cost, low- power, multifunctional and small size wireless sensor nodes that work together to sense the environment, perform simple data processing and communicate wirelessly over a short distance. In most current designs, sensors are randomly or uniformly distributed because of their simplicity. However, the node deployment has a great impact to the wireless systems. In this paper we present survey of node deployment in wireless sensor network. Node deployment in wireless sensor network is application dependent and can be either deterministic or randomized. But in both the cases coverage of interested area is the main issue. We discuss the random deployment, incremental deployment and movement assisted deployment algorithms and make comparisons between them. We present the characteristics of the environment in which the sensor networks may deploy.

Key words: Sensor deployment, wireless sensor networks, coverage etc.

1. Introduction

Sensor networks consist of a large number of small sensor devices that have the capability to take various measurements of their environment. These measurements can include seismic, acoustic, magnetic, IR and video information. Each of these devices is equipped with a small processor and wireless communication antenna and is powered by a battery making it very resource constrained. To be used, sensors are scattered around a sensing field to collect information about their surroundings. For example, sensors can be used in a battlefield to gatherinformation about enemy troops, detect events such as explosions, and track and localize targets. Upon deployment in a field, they form an ad hoc network and communicate with each other and with data processing centers.Here, deployment is concerned with setting up an operational sensor network in a real-world environment. In many cases, deployment is a labor-intensive and awkward task as environmental influences trigger bugs or degrade performance in a way that has not been observed during pre-deployment testing in a lab.When we come to the QoS problem of the WSNs, a research topic on the deployment of sensors has long been studied. The deployment of sensors in target field determines the topology of the network, which will further influence the coverage and efficiency of WSNs. The coverage control problem, which results from the deployment, has become one of the fundamental research topics of WSNs.

In this study, we discuss various sensor deployment, random deployment, incremental deployment and movement assisted deployment. In this, we review prominent wireless sensor network installations and problems encountered algorithms, which are classified into random during their deployment.

The paper is organized as follows. The next section is dedicated to primary objective for deployment schemes. In section 3 we turn our attention to different techniques of deployment scheme, we highlight the technical issues and describe published techniques which exploit node repositioning to enhance network performance and operation. Finally, Section 5 concludes the paper.

2. Primary Objective for Deployment

Sensors should be deployed in a way that aligns with the overall design goals. Therefore, most of theSensors should be deployed in a way that aligns with the overall design goals. Therefore, most of the proposed node deployment schemes in literature have focused on increasing the coverage, extending the network lifetime and boosting the data fidelity.

2.1 Area coverage

Maximal coverage of the monitored area is the objective that has received the most attention in the literature. Coverage can be classified into three classes; area coverage, point coverage and barrier coverage. Area coverage, as the name suggest is on how to cover an area with the sensors, while point coverage deals with coverage for a set of points of interest.

Decreasing the probability of undetected penetration is the main issue in barrier coverage. The objective is to maximize the coverage percentage; ratio of area covered by at least one sensor to the total area of the region of interest (ROI). Coverage problem in WSN basically is caused by three main reasons; not enough sensors to cover the whole ROI, limited sensing range and random deployment.

2.2 Network connectivity

Network connectivity of a sensor network is the objective which takes transmission range Tr and sensing range Sr into accounts. In early works network connectivity has been deemed a non-issue because of the assumption that the transmission range Tr of a node is much longer than its sensing range Sr. The premise is that good coverage will yield a connected network when Tr is multiple of Sr. However if the communication range is limited i.e. Tr = Sr, connectivity becomes an issue.

2.3 Network Lifetime

Extending the network life time is one of the main objectives of network deployment schemes. The positions of nodes significantly impact the network lifetime.For example, variations in node density throughout the area can eventually lead to unbalanced traffic load and cause bottlenecks. In addition, a uniform node distribution may lead to depleting the energy of nodes that are close to the base-station at a higher rate than other nodes and thus shorten the network lifetime.

2.4 Data fidelity

Ensuring the reliability of the gathered data is obviously an important design goal of WSNs. A sensor network basically provides a collective assessment of the detected phenomena by fusing the readings of multiple independent (and sometimes heterogeneous) sensors. Data fusion boosts the fidelity of the reported incidents by lowering the probability of false alarms and of missing a detectable object. We can increase the accuracy of fused data by increasing the number of sensors in that particular area but it will lead to more redundancy. However, redundancy in coverage would require an increase node density, which can be undesirable due to cost and other constraint.

3. Deployment Methodologies

The position of node has a dramatic impact on the effectiveness of the WSN and the efficiency of its operation. There are two methodologies for deploying sensor nodes in any interested area.

3.1 Static Positioning of Nodes

Node placement schemes prior to network startup usually base their choice of the particular nodes' positions on metrics that are independent of the network state or assume a fixed network operation pattern that stays unchanged throughout the lifetime of the network. Examples of such static metrics are area coverage and inter-node distance, among others. Static network operation models often assume periodic data collection over preset routes. etc.

Here in this methodology, placement decision is made at the time of network setup and does not consider dynamic changes during the network operation.

3.1.1 Deterministic Deployment

Deterministic coverage means that the placement is well controlled so that each node can be deployed at a specific position. The predefined deployment patterns could be uniform in different areas of the sensor field or can be weighted to compensate for the more critically monitored areas. This case is similar to the art gallery problem [11] (i.e. the problem is formulated as an art-gallery model for which the fewest guards are to be placed to monitor a gallery) and usually the suboptimum solution can be obtained by heuristics methods. Grid-based sensor deploymentis an instance of uniform patterns in which nodes are located on the intersection points of a grid. Chakrabarty et al. [12] presented different grid coverage strategies for effective surveillance and target location.

In [13], a centralized deterministic sensor deployment method, DT-score is the basis. Given a fixed number of deployable sensors, DT-score aims to maximize the area coverage of sensing area with obstacles. In the first phase of DT-score, a contour-based deployment is used to eliminate the coverage holes near the boundary of sensing area and obstacles. In the second phase, a deployment method based on the Delaunay Triangulation is applied for uncovered regions. Before deploying a sensor, each candidate position generated from the current sensor configuration is scored by a probabilistic sensor detection model.

3.1.2 Random Deployment

The nodes to be deployed are randomly distributed in an unknown or inaccessible area with unmanned devices or airplanes. In this scenario, the nodes have to discover their neighbors by themselves. This type of node placement is called random Deployment [8]. The random coverage scheme can be uniform, Gaussian, or Poisson, or may follow other distributions, depending on the application under consideration.
Ishizuka and Aida [9] have investigated random node distribution functions, trying to capture the fault-tolerant properties of stochastic placement.

They have compared three deployment patterns (Fig. 4, from [9]): simple diffusion (two- dimensional normal distribution), uniform, and R-random, where the nodes are uniformly scattered with respect to the radial and angular directions from the base station. While a flat architecture is assumed in [9], Xu et al. consider a two-tier network architecture in which sensors are grouped around relaying nodes that directly communicate with the base-station [10].A weighted random node distribution is then proposed to account for the variation in energy consumption rate in the different regions. The weighted random distribution increases the density of relays away from the base-station to split the load among more relays and thus extends their average lifetime.

3.2 Dynamic Repositioning of Nodes

Most of the protocols describe above initially Computes the optimal location for the nodes and do not consider moving them once they have been positioned.

In dynamic repositioning the nodes, while the network is operational is necessary to further improve the performance of the network. For instance, when many of the sensors in the vicinity of the base-station stop functional due to the exhaustion of their batteries, some redundant sensors from other parts of the monitored region can be identified and relocated to replace the dead sensors in order to improve the network lifetime. Such dynamic relocation can also be very beneficial in a target tracking application where the target is mobile. For instance, some of the sensors can be relocated close to the target to increase the fidelity of the sensor's data.
For the dynamic repositioning of node all techniques are divided into two parts:

3.2.1 Post Deployment Sensor Relocation

In this type of relocation scheme, relocation decision takes place when the sensor nodes are being positioned in the area. As we see, in most WSN application sensor deployment is performed randomly. But this type of deployment does not provide adequate coverage of the area unless more number of nodes is deployed. Alternatively, coverage quality can be improved by moving the sensor node to fill the coverage hole in the sensed area.

Wang et al. [1] utilizes each sensor's ability to move in order to distribute them as evenly as possible. In his study Wang et al. (2006) uses voronoi diagram to discover the coverage hole once all the sensor have been initially randomly deployed in the target area. Two sets of distributed protocols used to calculate the optical position of the mobile sensor nodes. In this a node needs to know the location of its neighbors to constructs voronoi polygons. To assess the coverage, a sensor node creates a Voronoi polygon with respect to neighboring sensors, as illustrated in Fig 1. Every point inside a Voronoi polygon is closer to the sensorof that polygon, i.e., Si in Fig. 1, than any other sensor.

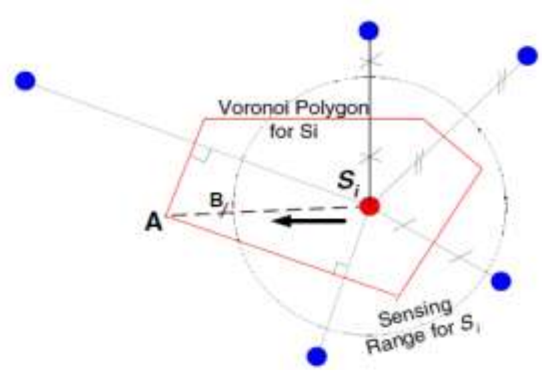

Fig 1: Sensor Si forms a Voronoi polygon with its neighbors

The intersection of the disk that defines the sensing range and the Voronoi polygon represents the area the sensor can cover. If there are uncovered areas within the polygon, the sensor should move to cover them. At each iteration every sensor node moves to an improved location and then the voronoi diagram reconstructed (Fig 2).

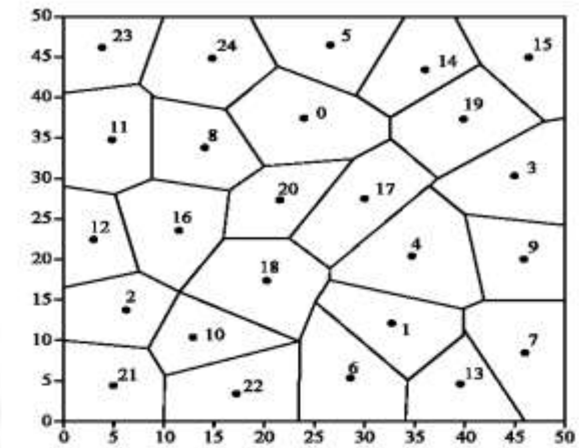

Fig 2: Sensors pursue relocation iteratively

In order to decide where to reposition a sensor, three methods have been proposed: VECtor based (VEC), VORonoi-based (VOR) and Minimax algorithm.

2	1	3	2	1	4
2	22	3	8	18	55
1	12	2	5	1	3
7	3	2	1	3	2
5	1	3	19	77	21
8	7	10	4	10	5

2	2	2	2	2	2
17	17	17	17	17	17
4	4	4	4	4	4
3	3	3	3	3	3
22	22	22	22	22	22
7	7	7	7	7	7

10	10	10	10	10	10
10	10	10	10	10	10
10	10	10	10	10	10
10	10	10	10	10	10
10	10	10	10	10	10
10	10	10	10	10	10

Fig 3: Steps of SMART a) Initial 2D clustering b) Row scan c) Column scan

The main idea of the VEC method is borrowed from electromagnetic theory where nearby particles are subject to an expelling force that keeps them apart. In the context of WSNs, virtual forces are applied to a sensor node by its neighbors and by the boundaries of its Voronoi polygon in order to change its location.

While in VEC the nodes are pushed away from the densely populated areas, VOR pulls the sensors to the sparsely populated areas. In VOR, the sensor node is pulled towards the farthest Voronoi vertex to fix the coverage hole in the polygon. However, the sensor will be allowed to travel only a distance that equals half of its communication range. This prevents the node from stepping into the area handled by another sensor that was out of reach prior to the move, which can lead to an unnecessary move backward later on.

In Minimax, the sensor keeps track of distances to all the vertices and finds a target position inside the polygon from where the distance to the farthest vertex is minimized. The Minimax scheme is more conservative in the sense that it avoids creating coverage holes by going far from the closest vertices, leading to a more regularly shaped Voronoi polygon.

Here sensor relocates its position from one place to other in rounds that cause the sensor to zigzag rather then move directly to final destination.

In order to shorten the total travel distance, a proxy based approach is proposed in [2]. In this approach, the sensor nodes do not move physically unless their final destination is computed. The authors consider a network with stationary and mobile sensors. Mobile nodes only move logically and designate the stationary sensor nodes as their proxies. This approach reduces the total and average distanced traveled by mobile nodes while maintaining the same level of coverage as [1].
Another representative study utilizing the computational geometry is the ISOGRID (ISOmetric GRID-based algorithm), by Lam and Liu, 2005 [3].

This study is less complex than the voronoi method since it simply considers the ideal coverage pattern, ISOGRID. In this distributed algorithm, each sensor calculates the magnitude and relative orientation of the force that exerts on its neighbors so as to form an ISOGRID. Here in this approach each node is Simultaneously driven by all its neighbors to various directions and magnitudes. The movement of a certain node is defined by the vector summation of all the driving motions imposed on it.
With the objective of reducing the overall deployment time, Wu et al. have proposed another solution to the same problem based on two dimensional scanning of clustered networks, called SMART [4]. A hybrid approach based on clustering is used for load balancing, where the 2-D mesh is partitioned into 1-D arrays by row and by column. Two scans are used in sequence: one for all rows, followed by the other for all columns. Within each row and columns, the scan operation is used to calculate the average load and then to determine the amount of overload and under load in clusters. Load is shifted from overloaded clusters to under load clusters in an optimal way to achieve a balanced state. Each cluster covers a small square area and is controlled by cluster head, knows the information about cluster's position in the 2-D mesh and the number of sensors in the cluster.

Sensor node deployment method based on a centralized virtual force [5], which combines the idea of potential field and disk packing. In this a powerful cluster head, which communicate with all the other sensors, collect sensor position information, calculate forces and desired position for each sensor. The distance between two adjacent nodes when all nodes are evenly distributed is defined as a threshold to distinguish attractive or repulsive force between two nodes. The force between two nodes is zero if their distance is equal to the threshold, attractive if less than and repulsive if greater than. The total force on a node is the sum of all the forces given by other sensors together with obstacles and preferential coverage in the area. The drawback of the VFA approach is also obvious, which is the general problem associated with a centralized approach.

In VFA, a powerful cluster head is required for collecting the sensor locations and determine the target location of the mobile sensors. However, in many sensor deployment environments such as disaster area and battlefields, a base station may not be available. Further, centralized approaches introduce the danger of a single point failure.

Before VFA algorithm, Howard et al (2002) [6] introduced a potential field based approach for self-employment of mobile sensor network. Nodes are treated as virtual particles and the virtual forces due to potential field repel (no attraction) between the nodes and the obstacles. There is communication required among the nodes. Here nodes only use their sensed information in making decision to move, making it a cost effective solution to the coverage problem. A final static equilibrium status is guaranteed.

3.2.2 On-demand Repositioning of sensors

Instead of relocating the nodes at the deployment phase, sensors can be relocated on demand to improve certain performance metrics such as coverage or network lifetime. This can be decided during the network operation based on the changes in either application-level needs or the network state. Or there may be a instance in which application can betracking a fast moving target which may require repositioning of sensor nodes based on the new location of the target.

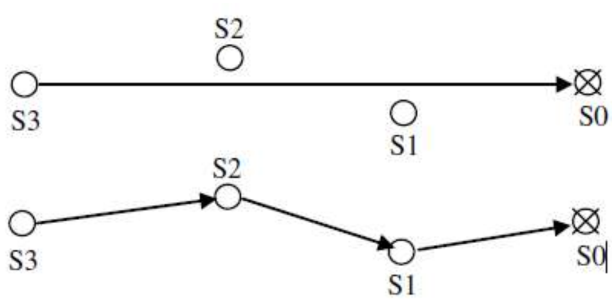

Fig 4: cascaded movement of nodes

Table 1: comparative analysis of different deployment techniques

Category	Proposed Schemes	Authors	Main Drawbacks	Distributed Vs Centralized	Termination Condition
Random deployment					
	R-random deployment	Ishizuka, and M. Aida, 2004	More number of sensor required near base station	Distributed	Connectivity with base station
	Weighted random node deployment	Xu et al., 2005	may leave some relay nodes disjoint from the base-station	Centralized	Efficient node distribution
Deterministic Deployment					
	DT score	Chun Wu, Kuo and Yeh-Ching Chung,	Priory knowledge, single point failure	centralized	Coverage with obstacle
	Potential field scheme	Chakrabarty, K. et al.,2002	Connectivity maintenance	Distributed	Energy depletion
Dynamic Deployment	Proxy based	Wang et al., 2004	Increases message complexity, very slow	Distributed	Local coverage
	Minimax	Wang et al., 2006	Energy constraint, Zigzag movement of sensor node	Distributed	Local coverage
	ISOGRID	Lam and Liu, 2005	Cannot handle obstacle	Distributed	Equilibrium state of sensor nodes
	SMART	Wu et al., 2005	Clusters without any sensors, prior knowledge of nodes	distributed	Coverage hole
	VFA	Zou and Chakrabarty,2003	Single point failure	Centralized	Over all coverage
	Flip based	SriramChellappan, XiableBai, Din Ma and Dong Xuan,	Determine the optimal way	distributed	Coverage hole

Limited motilities based approach is discussed in [7], where sensor can flip (or hop) only once to a new location and the flip distance is bounded. In this framework, the problem is to determine the optimal way for flip based sensors to maximize the coverage in the network. After detecting the coverage holes, the sensors move to new position to prevent coverage hole. Such movement can be realized in practice by propellers that are powered by fuel, coiled springs that unwinds for flipping. In this model, sensors can flip only once to a new location. Since moving a node over a relatively long distance can drain a significant amount of energy, a cascaded movement is proposed. The idea is to determine intermediate sensor nodes on the path and replace those nodes gradually. That is, the redundant sensor will replace the first sensor node on the path. That node also is now redundant and can move to replace the second sensor node, and so on.

4. Conclusion and Future Works

In this survey we discussed many existing node deployment strategies in wireless sensor network. We first introduce the WSNs generally and shed some light on importance of deployment problem. Then we begin with several objectives for developing an efficient algorithm for sensor node deployment. Then after we classify all deployment patterns into two parts static and dynamic. We respectively discuss the feature and representative work. There are still many challenges that need to be solved in sensor networks.

For future study these protocols need to be improved or new protocols developed to address higher topology changes and higher scalability.

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