# A Survey of Deterministic Vs. Non-Deterministic Node Placement Schemes in WSNs

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*Abstract*—**In Wireless Sensor Networks (WSNs), the node's position determines the functionality, life span and the efficiency of the network. The choice of the deployment strategy is crucial in most mission critical application areas. This paper examines the issues surrounding the choice of sensor placement schemes with respect to the application areas, type of sensors and the operational environment. Simulation results, based on hierarchical data clustering algorithm , reveal the effect of both deterministic and non-deterministic sensor placement strategies on the lifespan of a network formed using homogeneous sensors. The results corroborate the widely held view that deterministic sensor placement schemes usually outperforms non-deterministic methods, due to the higher level of control available to the network designer in the former than in the later approaches.**

**Keywords-** sensor; deterministic; non-deterministic; deployment.

## I. INTRODUCTION

Sensor nodes deployed with the intention of being operated autonomously in unattended environments like an oil pipeline running through hundreds or even thousands of miles presents a non-trivial challenge. In many configurations, it is normally envisioned that the wireless sensor networks (WSNs) should consist of hundreds or thousands of nodes, each operating on a small battery that stops working whenever it runs out of energy [1]. The WSN could fail to function should a significant number of those sensors exhaust their on-board energy supply. In certain applications and deployment schemes, failure of the critical node could result in the termination of the network's life [2]. Therefore, it is proper to carefully plan, design and manage WSNs in order to meet the application's requirements such as energy conservation which helps to prolong the overall lifespan of the network.

The choice of a sensor deployment scheme is often affected by the type of sensors, the application and the operational environment of the sensors [3]. The need to exercise control over node deployment is governed by the monetary and operational costs of the nodes and when their position in the network significantly affect their operation.

There are many perspectives under which the sensor placement problem could be viewed. The common ones include nodes function in the network, the optimization objective and the deployment methodology [4]. From the deployment point of view, we could classify the sensor placement problem into two namely, non-deterministic and deterministic placements.

Non-deterministic sensor placement is often referred to as random placement, while deterministic placement is often called controlled placement in some texts. In this paper, we would refer to random sensor placement as non-deterministic placement while controlled placement would be referred to as deterministic placement.

In Deterministic Sensor Placement Schemes (DSPS) [5], the nodes are placed in order to meet some desired performance objectives. For example, the coverage of the monitored region can be ensured through careful planning of node densities and fields of view and thus the network topology can be established at setup time. DSPS are common in certain applications like room temperature monitoring, medical applications, underwater acoustics, imaging and video sensors among others.

In many wireless sensor network applications however, the sensors are deployed randomly. In this placement scheme, there is little control over coverage and node density distribution to ensure strongly connected network topology [6]. Therefore, DSPS is often pursued for only a selected subset of the deployed nodes with the aim of structuring the network topology in a way that achieves the desired application requirements. Besides coverage, the node's positions in the WSN affect a number of network performance metrics such as energy consumption, delay and data throughput. For example, the signal strength gets attenuated with increase in distance from the transmitting node.

The remainder of the paper is organized as follows: Section II presents related work on sensor placement; Section III discusses some selected deterministic and non-deterministic sensor placement algorithms and Section IV highlights the factors that influence the choice of sensor node placement schemes. Finally, section V concludes the paper and points the way forward for our future work.

## II. RELATED WORK

Sensor placement is an area that has been well researched over the years [7] [1] [6]. In indoor applications, the sensor placement problem closely resembles the art gallery problem (AGP) which is aimed at determining the minimum number of guards needed to cover the interior of an art gallery [8].

In most of the literature, the problem is often viewed as an optimization problem that aims to meet some specific sets of objective function(s) such as coverage of a well-defined physical topology; coverage of a specific target of interest; network connectivity or maximization of the network's life span as the case may be.

Sensor placement in WSN presents a serious challenge in most of the non-trivial applications. The researchers in [8], showed that sensor placement problem is NP-hard. As a result of the complexity involved, [7] [9] proposed several heuristics aimed at finding sub-optimal solutions to the problem.

The position of a sensor node in a WSN can be viewed from three different perspectives namely; the deployment methodology, the optimization objective and the role of the node in the WSN [4]. Fig. 1, summarizes the different perspectives under which a sensor node can be viewed. A node is either deployed deterministically (i.e., when the node is carefully and deliberately positioned to serve its purpose) or non-deterministically (i.e. placement with little control over the actual positioning compared to deterministic method). When viewed in terms of its optimization criteria, the node could be to maximize the network lifespan, to ensure maximum area or network coverage, maximize connectivity or it could be to minimize energy wastage and so on. Moreover, a node in the sensor field could be viewed in terms of its function in the network. Here, the node could be serving the role of a sensor, a relay node( viewed in some cases as cluster head) or a data sink (i.e., terminal point where decisions on the sensed information is taken).

These optimization strategies are however based on the assumption that these sensors maintain static positions throughout the life time of the network so that the quality of service metrics such as distance, network connectivity can be measured with relative ease.

Some researchers in this area however, advocate for dynamic adjustment of the node's location. Their argument is based on the fact that the optimality of the initial node's positions in the WSN may become void during the life time of the network ( [10] [11]). This, in our opinion, is a valid point because external factors such as human activities (e.g., excavation) or environmental conditions (e.g., earth tremor), may change the initial locations of the deployed sensors. Moreover, network resources may result in changes as new nodes join the network, or as some existing nodes get exhausted and die out.

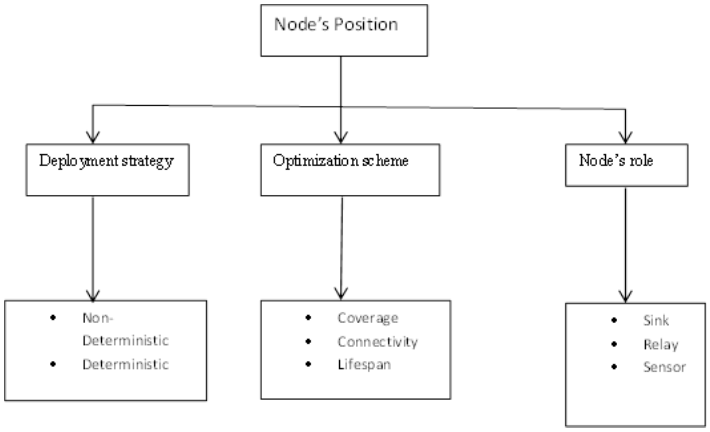

Fig. 1. Sensor Node Placement Strategies

Guo et al. [1] examined the impact of deterministic linear sensor placement on the life span of a wireless sensor network (WSN) deployed to monitor an oil pipeline using equal distance node placement scheme over different power configurations. They argued that by using only the right number of sensors, the life span of the WSN can be significantly enhanced. Any further addition to the minimal number of those sensors tends to worsen the lifespan of the network.

Shakkottai et al. [12] showed that it is possible to achieve optimal network connectivity without necessarily achieving area coverage. Their submission is based on the fact that disparity exists between the sensing and transmission ranges of a sensor . In practice these values are not always the same so, it is an important consideration that is equally related to the node deployment strategy. Examples of DSPS can be found in [13], where the sensors are used to monitor the health of buildings in order to detect corrosions and overstressed beams that can endanger the structure.

Similarly, varying the node density throughout the area of the sensor field can lead to unbalanced traffic load and hence bottlenecks. Likewise, a uniform node distribution may lead to depleting the energy of nodes that are closer to the base-station faster than those far from it, leading to shorter network lifetime [1].

## III. SENSOR PLACEMENT ALGORITHMS

DSPS in WSN is concerned with careful and controlled placement of sensors around the area of interest while non-deterministic on the other hand there is little control over the deployment at the target locations. In those WSN applications that employ DSPS algorithms, the positions of the sensors can be optimized to achieve the best coverage, connectivity or to maximize network lifetime as the case may be. This sensor placement strategy is common in most indoor and industrial applications where there is reasonable level of control on the node positions. Table III below depicts some sample references to node placement

| Reference | Type of coverage | Approach |
|---|---|---|
| [9] | Target | Objective is to minimize the number of deployed sensors in the network |
| [6] | Target | Algorithm is based on virtual forces (analogous to magnetic force of attraction on objects) |
| [14] | Area | Focus of maximizing area coverage; Algorithm is based on potential field; the number of neighbours of each sensor is required to be at least K. K, is number of communicating neighbours |
| [15] | Target/area | Focus on connectivity; Assumes equal communication and sensing ranges for all the sensors |
| [16] | Area | Considers connectivity; The algorithm works for arbitrary-shaped region and with any ratio of $r_c/r_s$, where $r_c$ is communication range and $r_s$ is sensing range |

TABLE I
Some Sensor Placement Algorithms

algorithms designed and implemented to address sensor area coverage, target coverage or both.

In [9], the algorithm uses path exposure (which is a metric), to estimate the likelihood that a target would be detected when it traverses through a sensor network. The metric is obtained by calculating the probability of detecting the target anywhere along the path. To obtain the probability, the total energy (E) that each sensor at position $i$ (i.e., $s_i$) could expend when detecting a target at position u is formulated as:

$$E_i(u) = \frac{K}{\|u - s_j\|^k} + N_i \tag{1}$$

where K is the energy emitted at the target, k is decay constant $(2 < k < 5), \|u - sj\|$ is the distance between the sensor $s_i$ and the target and $N_i$ is noise at $s_i$. The possibility of detecting a target event that occurred at position u is given by the probability that the total energy $\sum_{i=1}^{n} E(u)$ of all the n sensors, with reference to the target at u, is greater than a certain threshold $\eta$. This expression gives the probability that a target at location u can be detected by the network:

$$P_i(u) = Prob \sum_{i=1}^{n} E(u) > \eta \tag{2}$$

where $E_i(u)$ is as in equation 1 and $\eta$ is the detection threshold.

The monitored area is divided into a fine grids, and every edge in the grid is assigned a weight equal to $P_i(u)$ for all the points within that segment. Dijkstra algorithm is then applied to find the path with minimum weight as the least exposed.

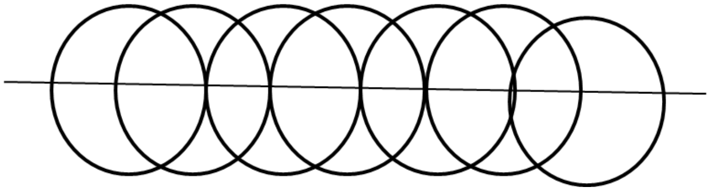

Fig. 2. Example of Sensor Placement Forming an r-strip

Zou and Chakrabarty [6], proposed the use of a virtual force and target location query. The idea is to use the virtual force to find the optimal location for a sensor after it is initially placed randomly in the sensor field. The operational principle of the virtual force is similar to that of the magnetic force which attracts opposite ends of the magnetic pole while it repels identical ends. The influence of this force on the sensors ensures coverage of the target location by moving them as far apart from their neighbor's as the force can possibly allow.

The same idea of the virtual force usage is further by extended by Poduri and Sukhatme [14], where they proposed two opposing forces $F_{cover}$ and $F_{degree}$, the former being that which makes neighbouring sensors repel one another to increase area coverage, while the latter is the force of attraction among the neighbouring sensors to maintain a threshold of $k$ connectivity ($k$ being the minimum number of nodes required to maintain simultaneous connectivity). Consequently, the eventual position of any sensor in the network is determined by the net force (i.e., $F_{cover} + F_{degree}$) acting on that sensor. Intuitively, it is easy to see that under this scheme, a deployed sensor node would maintain its fixed position until at least one of its neighbours die out or if some external barrier or force tends to break this equilibrium. In our opinion, it is not energy efficient to use this node deployment strategy for unattended outdoor application areas for obvious reasons.

Different from the schemes in [6] and [14], the authors of [15] examine the classical case of deterministic placement of nodes in an r-strip (i.e. with equal sensing and communication radii for all the deployed sensors). Their work is aimed at properly placing the sensors to achieve connectivity, coverage and to minimize the overall number of sensor nodes. The r-strip is as shown in figure 2, where the sensors are placed side by side and the distance between any two adjacent sensors is given by r. The overlapping circular rings represent the sensing and communication radii for each sensor.

Non-deterministic sensor placement is common in such application areas as disaster recovery and forest fire detections and other mission critical applications where it is quite risky and/or infeasible to use deterministic deployment strategies.

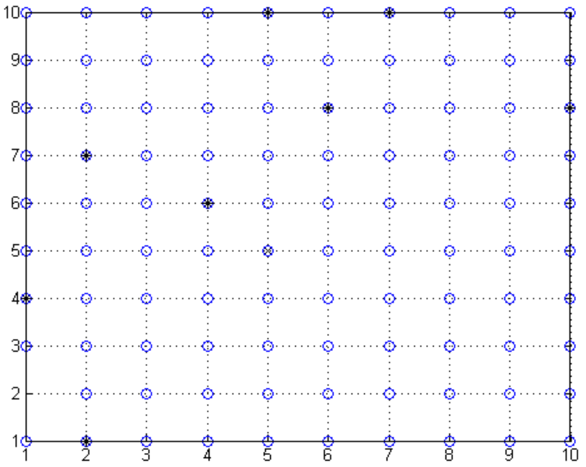

Fig. 3. DSPS Method

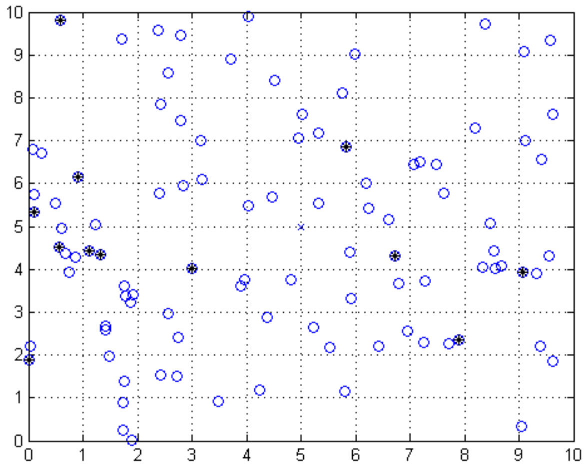

Fig. 4. Non-DSPS Method

## IV. RESULTS AND DISCUSSIONS

In comparing the performance of DSPS against its non-DSPS counterpart, LEACH [17] algorithm was used with the following parameters: $n = 100$ (i.e., the number of nodes); the topology is given by a $10x10$ 2-dimensional grid and $r$=500 (i.e., the number of rounds for executing the algorithm ). The data fusion center was situated at a fixed location within the sensor field while the nodes were deployed randomly (in the first case) and then deterministically (in the second case) respectively.

Recall that the LEACH algorithm proceeds in two phases namely, the network setup and the steady state phase. The network setup phase is comprised of the node deployment and initialization activities. Therefore, the sensor field for the DSPS method, was set up as shown in Fig. 3, where the nodes were carefully placed at evenly spaced grid points. This type of deployment is common in field surveillance applications (e.g., agriculture).

In a similar manner, the non-DSPS method was also set up as depicted in Fig. 4 with equal number of nodes on the same topology as in the case of the DSPS method.

The result in Fig. 5 shows the result of comparing the two deployment strategies in terms of the number of nodes whose energy are exhausted at each round of the algorithm. It is obvious that the DSPS method out performs against the non-DSPS method in terms of the number of dead nodes per round. This is indicative of the level of control that is inherently available to the network designer when DSPS method is used compared to non-DSPS methods.

In addition to the network performance indicators that correspondingly vary with the node deployment strategy in use, there are other important factors that govern the choice of any particular sensor node deployment scheme. Some of these factors are highlighted below:

(a.) Type of sensor:

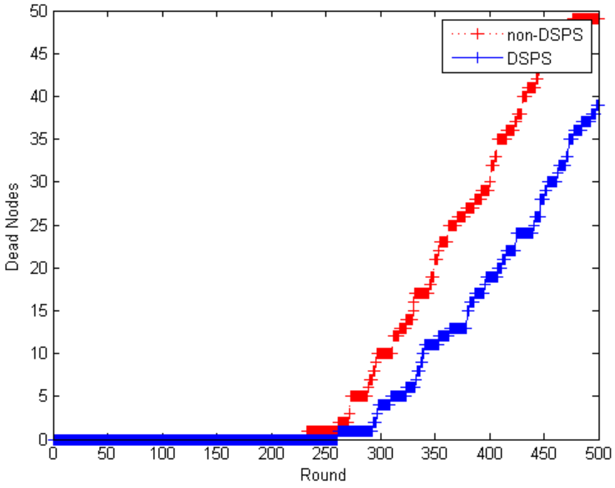

Fig. 5. Using LEACH to Compare DSPS With Non-DSPS

The type of sensor determines how it could be deployed. For example, heat sensors (thermal) cannot be deployed to measure wave amplitude (acoustic) because doing so would not yield the desired results. There are many dimensions to the type of sensor. Some of which include detection means, sensor material, size, weight, etc.

(b.) Application area:

Next to the type of sensor is the intended application area. In applications such as domestic appliances, personal health or scientific measurement, deterministic placement schemes are advisable while in military surveillance in enemy territories, forest fire detection, seismic sensing, etc., non-deterministic approaches are advisable.

(c.) Cost:

Cost is a general terms which is subject to interpretation based on the context. Here, we limit the word to the monetary cost of acquiring and maintaining the sensor node while in operation. For example, non-deterministic sensor node deployments are very common in application areas where the costs of the sensors are insignificant whereas, deterministic approaches are the norm in areas where the costs are high.

## V. CONCLUSION

One substantive contribution of this paper is in corroborating the widely held view that the choice of sensor deployment strategy directly affects network performance. The paper also highlights the factors that influence the choice of node deployment strategies in wireless sensor networks. Notable among these factors include the optimization criteria of the network and the role of the node in the network. Other factors include the type of sensor, the application area and the acquisition and operational costs of the nodes.

Whenever the application requires massive number of sensors in potential target areas, and the cost of the nodes is insignificant, we opined that non-deterministic placement strategies are more practical. For example, when using a sensor network to monitor an oil pipeline running through thousands of miles or for security surveillance purposes, employing the non-deterministic deployment strategy would be highly recommended in order to meet certain acceptable performance objectives such as coverage and connectivity. This paper focuses its investigation on sensor node deployment strategies in WSNs only. It does not cover other types of nodes serving different roles (e.g., relay nodes or base station nodes) in the network.

We envision that a mix of both deterministic and nondeterministic sensor placement schemes would be the most effective and efficient placement strategy for large-scale and mission-critical WSN applications where inexpensive nodes could be deployed to serve the roles of sensors in the monitored region while few, more powerful nodes could serve the roles of data relay nodes in the network to save energy. In our future work, we plan to embark on the comparative analysis of sensor placement and data fidelity in WSN using some tested models.

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