An Approach for Sensor Placement to Achieve Complete Coverage
and Connectivity in Sensor Networks

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Abstract—**The main objective required for a Wireless Sensor Network (WSN) is the positioning of the sensor nodes to form a WSN. There are two strategies for the positioning of nodes in an area of interest where some phenomena are to be monitored: deterministically or randomly. In this paper, our goal is to propose a new sensor placement technique, which is based on random distribution with coverage and connectivity constraints.**

Keywords–Placement; Random; WSN; Coverage; Connectivity.

I. INTRODUCTION

Recent developments could not be achieved without a change in the field of communication. Mainly Wireless Sensor Networks (WSN) and mobile computing become more and more popular. Control of environmental parameters can give rise to several applications. In the monitoring area, the WSN is deployed over a region where some phenomena have to be monitored. The nodes can be equipped with sensors to measure temperature, humidity, and gases.

A WSN consists of a number, often significant, of sensors with limited perception and communication capabilities where each node is connected to one (or sometimes several) sensors. There exist two types of sensors: homogeneous sensors, which possess the same communication and computation capabilities and heterogeneous sensors, which possess different capabilities. Determining the sensor field architecture is a key challenge in sensor resource management. Sensors have to be placed at critical locations that provide sustainable coverage.

Many works for sensors and sensor placement were done. In [1], Lin models the sensing field as a grid points. Then, he explains how to place sensors on some grid points in order to satisfy a particular quality of service based on the Simulated Annealing approach. Using the genetic algorithm, the authors in [2] propose an approach for the sensor placement problem. In [3], the Improved Particle Swarm Optimization (IPSO) algorithms have been employed to determine the optimal sensors number and configurations.

Recent works focused on relay placement algorithm to determine the set of positions which can guarantee connectivity. The main objective of the work proposed in [4] is to reduce the set of locations for the existing mobile nodes in the network to the locations of relay nodes that would ensure connectivity with the least count. A multi-objective mathematical model is used to determine the best placement of mobile nodes for different tasks [5]. In [6], Flushing proposes a combination of exact method and heuristic method to solve the problem mentioned below. Thus, his work was based on Mixed-Integer Linear Programming (MILP) and a Genetic Algorithm (GA).

A related problem to the deployment in WSN is Art Gallery Problem (AGP) addressed by the art gallery theorem [7]. The AGP problem consists of determining the minimum number of guards to cover the interior of an art gallery. Many researches for the AGP have been discussed in literature. There exist some similarities between our sensor placement problem and the AGP, such that the guards (sensors in our case) are assumed to have similar capabilities.

As we mentioned earlier, there exist two ways for the placing of sensors with random placement or with grid-based placement. The former one is defined as a technique where nodes are deployed at random positions. The latter is defined as the one where sensors are placed exactly at pre-engineered positions. Figure 1 shows the different categories of node placement strategies.
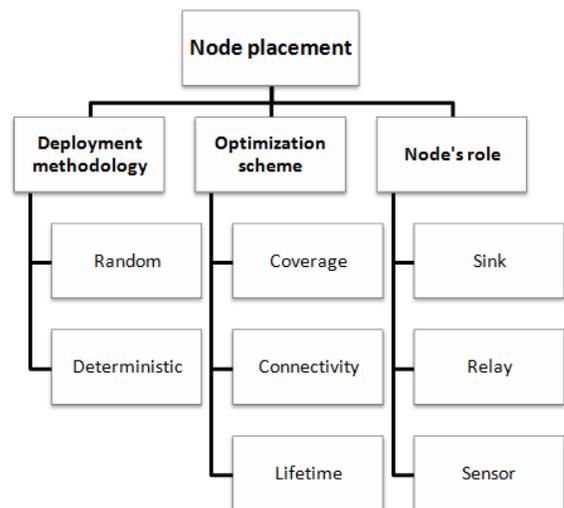

Figure 1. Sensor node placement methodologies

On the other side, the authors in [8] classify the place-

ment strategies into static and dynamic depending on whether the optimization is performed at the time of deployment or while the network is operational, respectively. In [8], Younis assumes that the choice of the deployment scheme depends on many properties. Thus, many researches assume that for some cases, the random placement becomes the only option due to environment characteres [1] and deployment cost and time [9]. This paper focuses on the implementation of an optimal node deployment strategy based on a random placement method. The remaining part of this paper is organized as follows: Section 2 starts by summarising the problem of the sensor placement. Our sensor placement approach is then presented in Section 3. Section 4 shows the results of our procedure. Section 5 provides our conclusions.

II. PROBLEM STATEMENT

The problem addressed in this paper has as objective to determine minimum number of sensors when the maximum of targets are covered. There are two strategies of sensor node placement: deterministic or non-deterministic (random). We assume our goal is to deploy the sensors in order to provide the connectivity and the coverage of the service area. Thus, the main objective of our approach is to ensure that the maximum of the area is covered. The authors in [10] formulate a constrained multivariable nonlinear programming problem to deploy the sensors in their locations under constraints of network lifetime and total power consumption. They propose two optimal placement strategies to this problem.

The number of the sensors is determined by taking into account both the coverage of the area of interest and the communication between sensors in the WSN. Thus, communication in a WSN is an effective and practical way to improve the system performance of WSN. This suggests that both the network connectivity and the coverage are an essentiel parameter which must be taken into account when positioning sensors. Each deployed sensor should be able to cover an area in order to increase the coverage in a defined region while maintaining the connectivity in the WSN.

III. METHOD

Sensor placement can greatly impact the WSN performances, such as coverage and connectivity. The former is defined to quantify the quality of service (QoS). The latter answers the questions about the communication network in a WSN. Table I introduces the parameters used during our work.

TABLE I. PARAMETERS OF THE WSN.

Parameter	Definition
C_i	Node i
R_s	Node sensing radius
R_c	Node communication radius
A	Network area
A_i	Area of the Voronoi polygon for a sensor
N	Number of sensor nodes in the network
C	Coverage of the total area
D_{ij}	Distance between nodes i and j
N_e	Maximim number of neighbors

Minimizing the number of deployed sensors and maintaining higher sensor coverage when positioning the sensors have always been a challenge, especially when the monitoring region is unknown. The aims of the present article are to implement an approach for the sensor placement problem with coverage and communication constraints. The main goal of the sensor placement approach is to determine the best placement of the sensors. In addition, the proposed algorithm aims at achieving high sensor coverage while maintaining network connectivity.

We assume that a region A is covered if there exists a sensor at position p with sensing radius R_s that contains the region A completely [1]. Thus, the ability of detection varies with the distance between the sensor C_i and the target T_j [11] [12], mathematically speaking we have:

$$D_{i,j} \leq R_s \quad (1)$$

where $D_{i,j}$ is the distance between the position of the sensor C_i and the target T_j.

To guarantee node communication, The connectivity is assumed to be full if the distance between two sensors is less than the communication radius of the sensor. The distance is defined as the Euclidean distance between two sensors. Figure 2 shows a pseudo code of the algorithm.

```
Algorithm PLACE_SENSORS:
Step 0: deploy first sensor C_0 randomly
Step1: while a maximum coverage not achieved
Step2: generate a random position for sensor C_i
        Evaluate the distance D_ij between C_i and C_j (0 ≤ j < i)
        If exist C_j while D_ij ≤ R_c then
            If C_j 's neighbors ≤ Ne
                Deploy C_i
                Link C_i and C_j and go to Step1
            Else
                Go to Step2
            End
        Else
            Go to Step2
        End
End
```

Figure 2. Algorithm for sensors placement

We begin by generating a random position for the first sensor. Then, deploying the rest by taking into account a maximum coverage and connectivity in the area of interest as constraints. The number of neighbors of each deployed sensor should be less than a defined number N_e in order to ensure a sufficient distribution in the area.

Process node 1: deploys the first sensor randomly.

Process node i: node i is deployed if there is at least a link with node j ($0 \leq j \leq i - 1$) and a sufficient coverage not achieved yet.

The algorithm is iterative, and it places one sensor in the sensor field during each iteration. It terminates either when a sufficient coverage of the zone is achieved.

IV. SIMULATION AND RESULTS

The proposed method aims at defining the initial placement of sensors. All sensors have the same deployment parameters and have the same sensing coverage (R_c) and the same communication range (R_s). The former helps in the detection of the designed event. The latter is introduced for the connectivity of nodes with their neighborhoods. Thus, depending on the communication range the neighborhood of a node is defined. We say that the probability of communication between two nodes varies inversely with the distance between them.

We evaluate the proposed approach via simulations (NS2). Our topology is a square with total area A = 20 x 20, A_i is the area of the Voronoi polygon for a sensor for a full sensing coverage and a full connectivity defined as [13]:

$$A_s(Cov, Con) = min(2R_s^2, R_c^2) \qquad (2)$$

Twenty seconds is considered as the simulation time. It should be mentioned that we assume that all links are bi-directional during simulation. The sensing range is set to 2 while the communication range is set to 4 and the maximum number of neighbors (N_e) for each deployed sensor is set to 4. Thus, each sensor must have a number of neighbors less than N_e (fixed to 4 in our case).

We assume that the algorithm stops when the coverage C is greater than 1, we define C as the ratio of the union of all areas covered by each node and the area of the entire Region Of Interest (ROI) [9]. The coverage C helps to ensure that the region is entirely covered by the sensors when deploying them. In this work, we try to take into account the overlapping zone between nodes when calculating the area covered by the sensors. Each node is characterized by a covered area which is defined as the circular area within its sensing radius R_s.

$$C = \frac{\cup_{i=1..N} A_i}{A} \qquad (3)$$

Where A_i is the area covered by the ith node,

N is the total number of nodes,

A stands for the area of ROI.

Our approach is used in order to determine a better methodology for sensor placement problem in a WSN. As for results, the number of sensors in the region of interest varies from 51 to 57 providing full sensing coverage and full network connectivity. We can observe that our approach outperforms Max_Avg_Cov [14] [15] and MIN-MISS [15] [16]. It is important to point out that in this work, we do not take into account obstacles in the ROI.

V. CONCLUSION

In this paper, the sensor placement problem is studied. We have formulated a new strategy for the initial sensor placement problem. We start with a random distribution of nodes with constraints of coverage and connectivity. As part of our future work, we would extend this result to a case when there are obstacles in the ROI. Thus, we assume that the above results are practical and can be used in actual sensor network design.

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