

Review Article

# Proposed Approaches for Sensor Node Deployment in Wireless Sensor Networks

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## Abstract

Sensor deployment is a crucial aspect of designing any wireless sensor networks. Deployment strategy significantly influences wireless sensor network performance. Various deployment strategies have been proposed to improve network connectivity and sensing coverage. Wireless sensor deployment is a complex problem that requires careful consideration of various factors, including the application, environment, energy consumption, and communication technologies. Different deployment methods and strategies can be used depending on the objectives and constraints of the sensor network. Many issues must be considered when proposing any sensor deployment approach. Most of these issues are coverage range, network connectivity, communication range, sensor location, and scalability. In this research, a random deployment approach is proposed to estimate the required number of sensors to be deployed in a certain area. A predefined deployment model is also developed to calculate the optimal number of sensors and their distribution coordinates based on grid deployment. A mathematical optimization model is proposed to find the optimum required number of sensor nodes to be distributed in a specific area by selecting the optimal sensors distribution among different places. This developed model is validated by different simulation experiments. It also aims to achieve maximum possible connectivity and maximum sensing coverage to offer a certain limit of consistency using minimum nodes number without long simulation experiments. This is achieved by enabling any sensor to communicate with one or more nearby sensors at any given time. The simulation results proved to be largely consistent with the results of the mathematical model.



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## 1. INTRODUCTION

Wireless Sensor Networks play a fundamental and essential role in modern control and monitoring systems. With advancements in information technology, the Internet of Things (IoT) applications, the introduction of 5G and 6G technologies, and the development of artificial intelligence, sensor deployment has become a smart process that considers reliable coverage, energy consumption, communication reliability, and low cost [1]. The deployment of wireless sensors refers to the distribution of sensor nodes within a defined area to achieve a specific objective. The quality of the deployment directly affects coverage, connectivity, power consumption, and data transmission reliability [2]. Wireless Sensor Networks (WSNs) are composed of numerous number of sensor nodes that have the capability to observe, communicate, and respond to any happened actions in a specific area of interest [3, 4]. The primary step in establishing a wireless sensor network is the deployment. The essential goal of deploying a WSN is to support data gathering from specific accessible or not accessible places. Sensors can be deployed in different ways depending on the optimization objective and the application situation [5].

WSNs need appropriate deployment of sensor nodes to guarantee to achieve optimal connectivity and coverage. Deployment approaches can be either deterministic deployment or random deployment. Deterministic deployment places the sensor nodes at predetermined locations, where as random deployment distributes the sensor nodes in an environment in a random manner [6]. Finding an optimal deployment plan is very difficult due to many practical factors affecting the WSN deployment approaches [7, 8]. Full coverage of the selected environment can be achieved in deterministic deployment by developing suitable models to select the required number of sensors. In random deployment, achieving a high level of coverage requires deploying several number of sensor nodes. Therefore, related works have proposed various deployment optimization algorithms to reduce the number of sensor nodes and the distance between the deployed sensors [9].



Planning the deployment of wireless sensors has become a crucial element in smart applications. They contribute effectively to smart city designs, healthcare, environmental monitoring, agriculture and industry, military applications, and intelligent transportation systems [3].

## 2. CHALLENGES

WSNs are becoming crucial in many applications, including the environment, industry, agriculture, healthcare, and the military. However, deploying WSNs comes with several challenges that need to be addressed to ensure the proper functioning and performance of the network. Special or developed techniques are important in carefully managing the process of node deployment. It is important to find and indicate the node location (coordinates) either before the predefined deployment or after the random deployment. One of the essential issues is ensuring the required level of total network coverage or sensing area [10, 11]. Power consumption and limited battery life are among the most significant challenges and limitations facing wireless sensor networks. Therefore, efficient performance have guaranteed by reducing power consumption and considering wireless recharging capabilities to keep these networks operational for extended periods [12]. Sensor networks suffer from security issues, data collection accuracy, and quality of service. Therefore, reliable data transmission and communication between sensors remain a major challenge in next-generation wireless sensor networks [11].

## 3. DEPLOYMENT APPROCHIES

Sensor deployment refers to the process of placing sensors in a specific area to collect data. There are different approaches of sensor deployment, including [13, 10]:

*Random deployment:* This approach is common in different applications [7]. It is forced to be used in case of unreachable or risky environments. Sensors are usually dispersed using an airdrop in this approach. Once deployed, the sensor nodes employ self-configuration protocols to organize themselves into an efficient wireless network. It cannot provide full coverage, and in many cases, additional nodes are required to be redeployed to achieve the desired network coverage area. Its main drawback is its inability to provide uniform distribution [14].

*Deterministic deployment:* Deterministic deployment approach is suitable to cover a required uniform sensing area, and the state of the application environment is identified. It can ensure a particular quality of service. The main goal of the deterministic deployment is to decrease the number of deployed sensors while guaranteeing communication among nodes and covering all the regions of interest [15]. This approach is sometimes called predefined deployment. It is unfeasible for large-scale networks or inaccessible zones due to its higher complexity and cost [16]. The following statements will present the proposed models for these deployment approaches.

The decision variables in this model include: deployment area, number of sensors, and coverage range. The objective function maximizes connectivity using the optimal number of sensors.

## 4. RANDOM DEPLOYMENT

Estimating the suitable number of sensor nodes to be distributed in a certain field to create a wireless sensor network is subject to the size of the deployed field, application type, and required level of sensing coverage. Random deployment adds a significant challenge in estimating the essential number of sensors to be installed. The essential number of sensor nodes to cover a deployed area using random deployment is usually greater than that required for predefined deployment. The suitable number of sensor nodes that are essential to observe a certain field in a random deployment can be estimated using simulation studies. Optimizing sensor node deployment in random deployment can improve the observed area. Addressing this estimation problem challenges requires optimization algorithms and the development of specific deployment strategies.

A proposed model can be created and used to estimate the required number of nodes to sense a specific area. This model uses the deployed area size, sensors coverage (sensing) and communication ranges, and required level of coverage to estimate the required sensor number.

***The model assumptions:***

*A = area size may be calculated as length width (Lw)*

*N = number of deployed sensors*

*Cr = coverage range*

*Cm = communication range*

*C = coverage level*

### The model:

As the sensor coverage area is a circle, the coverage for each sensor can be calculated by the circle area (let  $C_r$  be its diameter):

$$\text{One sensor coverage area} = \pi * C_r^2$$

$$N. \text{ Sensor coverage area} = N * \pi * C_r^2$$

A portion of the total area (a percentage thereof) can be subtracted due to the overlapping areas of adjacent circles. This percentage was calculated and found to be 0.011 of the total area.

The proposed equation to estimate the coverage level is as follows:

$$C = \frac{N * \pi * C_r^2}{A * 0.011} \leq 1 \quad \dots\dots\dots (1)$$

From equation (1):

$$N = \frac{C * A * 0.011}{\pi * C_r^2} \quad \dots\dots\dots (2)$$

### ○ Simulation experiments

Different simulation scenarios are implemented in net logo 6.1.1 to determine the essential number of sensors to cover a certain area size with different sensor coverage area values. In these simulation scenarios, different numbers of sensors are used, and different values of coverage for the sensors are used. These sensor nodes are randomly deployed in different area sizes. These scenario results are compared with the calculated results from the developed model to show its validity. (Table 1) presents the results after implementing the simulation experiments for the area of 200 \* 200 with different deployed number of sensors and various sensor coverage areas. It also showed the calculated results using the proposed mathematical model (Eq. 1).

**Table 1:** Simulation results for deploying different numbers in a 200 \* 200 m2 area.

| Number<br>of<br>sensors | C when $C_r = 0.8$  |                | C when<br>$C_r = 0.9$ | C when<br>$C_r = 1.0$ | C when<br>$C_r = 1.2$ |
|-------------------------|---------------------|----------------|-----------------------|-----------------------|-----------------------|
|                         | Using<br>Simulation | Using<br>Eq. 1 |                       |                       |                       |
| 80                      | 0.36                | 0.365          | 0.401                 | 0.56                  | 0.84                  |
| 100                     | 0.45                | 0.45           | 0.57                  | 0.72                  | 1.0                   |
| 120                     | 0.55                | 0.548          | 0.64                  | 0.84                  | 1.0                   |
| 130                     | 0.60                | 0.593          | 0.75                  | 0.92                  | 1.0                   |
| 140                     | 0.64                | 0.639          | 0.81                  | 0.95                  | 1.0                   |

The calculated results using equation 1 are very close to the simulation results. These calculations show the validity of the proposed mathematical model.

## 5. PREDEFINED DEPLOYMENT

Sensor location (position or coordinates) is the most important factor in the case of designing or building any new WSN, especially in accessible areas. Predefined sensor deployment places sensors in a regular pattern or shape. The essential number of sensors required to sense a specific area varies depending on the application and sensor characteristics. Deployment must achieve a good level of connectivity. WSN connectivity means the ability to communicate (reach) from each sensor to all others. It means there are either directly or indirectly links joining all the sensors in the network. Graph theory can be used in representing these nodes and their links as a connected graph. Creating a connectivity matrix (CMatrix) is proposed for estimating WSN connectivity.

The initial connectivity matrix represents a square  $n \times n$  adjacency matrix in which every row  $i$  and column  $j$ , its diagonal  $a_{ii} = 1$ , and its  $a_{ij} = \text{zero}$ . (Figure 1) shows the initial connectivity matrix form.

$$CMatrix = \begin{matrix} & \begin{matrix} 0 & 1 & \dots & n \end{matrix} \\ \begin{matrix} 0 \\ 1 \\ \vdots \\ n \end{matrix} & \begin{bmatrix} 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 \\ \vdots & \vdots & 1 & \vdots \\ 0 & 0 & \dots & 1 \end{bmatrix} \end{matrix}$$

Figure (1). The connectivity matrix (CMatrix).

The next step is to calculate the Euclidian distances ( $d_{ij}$ ) where  $i \neq j$ .

If  $d_{ij} \leq Cr$  then:

Replace the 0 value for points  $ij$  and  $ji$  with one in the CMatrix.

After completing all the matrix values, the WSN connectivity has been calculated by summing all the ones in all rows and divided it by  $(N^2 - N)$ .

## 6. GRID DEPLOYMENT

A grid deployment model is proposed in this paper. It gives a regular deployment with deterministic locations of the sensors. The grid model requires as few sensors as possible to achieve the required coverage. The main aim is to calculate the optimum number of sensors to sense a specific area as a grid. The following assumptions have suggested designing the proposed grid deployment model shown in (Figure 2).

- 1) Homogenous sensors are deployed in a square area.
- 2)  $L$  = square area dimension
- 3)  $P(X_i, Y_j)$  = node position
- 4)  $Cr$  = Sensor node sensing (Coverage) range

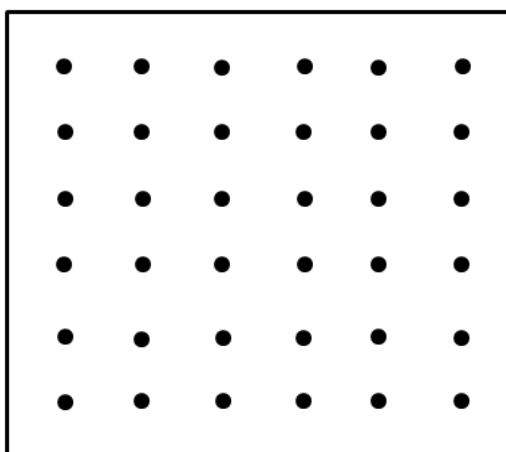


Figure (2). The grid deployment model.

The Model:

The number = of sensor nodes ( $n$ ) in each row can be estimated as follows:

$$n = \frac{L}{2Cr} + 1$$

The total number of sensors will be  $n^2$ .

$$\text{Distance among sensors (D)} = \frac{L}{n-1}$$

$P(X_i, Y_j) = P(0, 0) = (0, 0)$ , for  $i, j = 0$  (starting point)

$P(X_i, Y_j) = (X_{i-1} + D, Y_{j-1} + D)$ , for  $n \geq i, j > 0$

Example:

Let a WSN established on a square area of 500 m 500 m. The sensors coverage range has been suggested to be 62.5 m.

The number of required sensor nodes can be estimated as follows:

The number of sensor nodes ( $n$ ) in each row can be estimated as follows:

$$n = \frac{L}{2Cr} + 1 = \frac{500}{2 \times 62.5} + 1 = 5 \quad \dots\dots\dots(3)$$

**The total number of sensors will be 25.**

$$\text{Distance among sensors (D)} = \frac{L}{n-1} = 125 \text{ m}$$

$$P(X, Y) = 0, 0 \text{ when } X = 0 \text{ and } Y = 0.$$

$$P(0, 1) = P(0, 0 + D) = P(0, 125) = (0, 125)$$

$$P(0, 2) = (0, 125+125) = P(0, 250) = (0, 250)$$

.

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$$P(0, 5) = (0, 500)$$

$$P(1, 0) = P(0 + 125, 0) = (125, 0)$$

$$P(2, 0) = (250, 0)$$

.

.

$$P(5, 0) = (500, 0)$$

$$P(5, 5) = (500, 500)$$

Figure (3) shows the optimal grid deployment for this example.

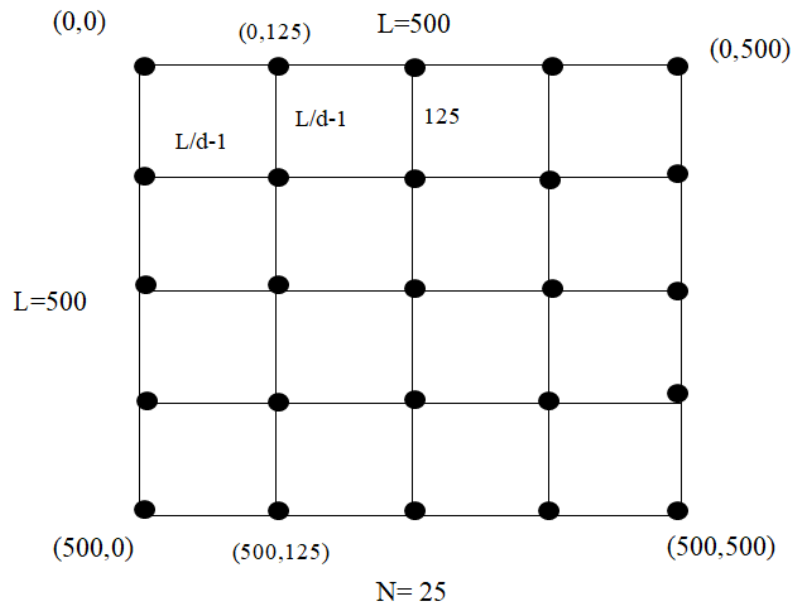


Figure (3). The optimal grid deployment for the example.

## 7. DEPLOYMENT STRATEGY SELECTION

Choosing the appropriate sensor deployment method for a specific application depends on various factors, including the application requirements, environment, and available resources [16]. Here are some considerations to help in the decision-making process:

1. Coverage requirements: If the application requires full coverage of the sensing area, deterministic or predefined deployment methods may be more suitable. On the other hand, if coverage requirements are not strict, random deployment methods can be more cost effective, although they may require a larger number of sensor nodes.
2. Application status: If the application status of the environment is known, deterministic-based deployment methods can be used, where sensor nodes are fixed at selected areas of the application to meet specific requirements. This method is suitable when the operation status can be fixed in the selection area of the wireless sensor network (WSN).
3. Accessibility and terrain: Consider the accessibility of the deployment area. In some cases, random deployment methods may be more appropriate, such as in inaccessible terrains, disaster areas, or war zones. However, in areas where deployment is difficult, it may be necessary to invest in a larger number of sensor nodes to achieve the desired coverage effect.

**Cost and resources:** Consider the available resources and budget for the sensor deployment. Random deployment methods may be more cost-effective in some cases, while deterministic or predefined deployment methods may require more planning and resources.

By considering these factors, you can choose the most appropriate sensor deployment method for your specific application, ensuring optimal coverage, connectivity, and cost effectiveness.

## 8. CONCLUSION

The WSN deployment process is a vital issue that requires proper planning and optimization. It can be performed in two methods: random and deterministic-based deployment. However, selecting an optimal deployment method is challenging due to many issues affecting it. Deterministic-based deployment methods can be used when the status of the environment is identified, and the sensor node can be installed at the area of interest. Random deployment methods can be used when the full sensing of the indicated environment is not needed, but numerous amounts of nodes should be distributed to achieve full coverage. Distances among sensors represent the crucial factor in each deployment method. Estimating the minimum number of sensor nodes suitable for offering good sensing level with the corresponding deployment scheme can be studied on the required area to be covered. The most important metrics are intersensor distances, among others. To deploy a suitable number of sensors in a square area, different numbers of sensors can be selected. Each selected number must have a square root integer value, for example (25, 49, 64, ..., 100). This value of the square root is the number of sensors in each area row or column. Overall, linear programming can be a useful tool for optimizing the deployment of sensors to achieve specific objectives. By making the problem as a linear programming model, it is possible to find the optimal solution that meets the desired criteria.

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## BIOGRAPHIES OF AUTHORS

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