

# Implementation of Coverage Problem in Wireless Sensor Network Based on Unit Disk Model

*A thesis submitted in partial fulfilment*

*of the requirements for the degree of*

**Bachelor of Technology**

*in*

**Computer Science and Engineering**

*by*

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## Certificate

This is to certify that the work in the thesis entitled *Implementation of Coverage Problem in Wireless Sensor Network Based on Unit Disk Model* by Pretty Sapna Tirkey in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Computer Science and Engineering during the session 2012-2013 in the department of Computer Science and Engineering, National Institute of Technology, Rourkela is an authentic work carried out by her under my supervision and guidance. To the best of my knowledge the matter embodied in the thesis has not been submitted to any other university/ institute for the award of any degree or diploma.

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# **Declaration**

I hereby declare that all the work contained in this report is my own work unless otherwise acknowledged. Also, all of my work has not been previously submitted for any academic degree. All sources of quoted information have been acknowledged by means of appropriate references.

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# Abstract

Wireless sensor networks (WSNs) have a wide range of applicability in many industrial and civilian applications such as industrial process monitoring and control, environment and habitat monitoring, machine health monitoring, home automation, health care applications, nuclear reactor control, fire detection, object tracking and traffic control. A WSN consists of spatially distributed autonomous sensors that cooperatively monitor the physical or environmental conditions including temperature, sound, vibration, motion, pressure or pollutants. In sensor networks where the environment is needed to be remotely monitored, the data from the individual sensor nodes is sent to a central base station (often located far from the network), through which the end-user can access data. The number of sensor nodes in a Wireless Sensor Network can vary in the range of hundreds to thousands. Such a network may have many challenges like low energy consumption, functional independence, efficient distributed algorithms, transmission routes, coverage, synchronization, topology control, robustness and fault tolerance, cost of maintaining the sensors and lifetime of the network.

In this project work I have concentrated on the coverage problem of a wireless sensor network. The transmission range of a sensor node is considered and graphs have been plotted to show number of nodes that are sufficiently when network size is varied.

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# List of Abbreviations

WSN	Wireless Sensor Network
AGP	Art Gallery Problem
PDA	Personal Digital Assistance
GPS	Global Positioning System
UC	Unit Coverage
NC	Non- Unit Coverage



# Chapter 1

## Introduction

*Introduction*  
*Thesis motivation*  
*Thesis Objectives*  
*Thesis Organization*  
*Summary*

# Chapter 1

## Introduction

### 1.1 Introduction

A wireless sensor network(hence forward referred as WSN) comprises of spatially conveyed self-governing sensors to detect physical or environmental changes in an area such as temperature, pressure, noise etc. and to co-operatively store the data at some location. The current systems are bidirectional (allowing control of sensor activities).

WSN started its use in military department where it was majorly used in supervising battlefield wings; today it has expanded its use in industries and consumer applications. The WSN is assembled of sensor hubs from a couple of hundreds to thousands and each one joined with the other.

### 1.2 Thesis Motivation

1. To describe and determine the deployment of wireless sensor networks when the sensor nodes have a unit disk sensing region.
2. The sensing region of sensor nodes varies from few hundred metres to several hundred metres. So to evaluate the performance of the algorithm using the given parameters:
  - (a) The sensor nodes are homogenous
  - (b) The sensors are static in nature (location)
  - (c) The sensors have unit disk sensing radius
3. To determine the performance of the algorithm when sensing range is varied and determine a percentage of region that is k-coverage in a given deployment area.

## 1.3 Thesis Objectives

- In mobile ad hoc networks (MANET) portability changes neighbourhood relationship which must be made up for. E.g., courses in the system must be changed in like manner
- Complicated by scale: Large number of such nodes troublesome to backing.
- Instead of centering communication on people, concentrate on collaborating with environment.
- Network is inserted in any area with many environmental variations.
- Nodes process data and convey it wirelessly.

WSNs May be advantageous in scenarios that combine

- Short sensor range: E.g., temperature, smoke detection
- Large area: E.g., forest, agricultural field, building
- High temporal/spatial variability: E.g., temperature in wildfire
- Event detection: intrusion detection in restricted areas.

## 1.4 Thesis organization

This thesis is organised into chapters 6 where we start by giving a brief introduction of the thesis. The remainder of the thesis is organised as follows.

Chapter 2 elaborates all about Wireless Sensor Networks. Its background, its features, its challenges, the components involved and architecture of a sensor node Chapter 3 throws light on the primary objective of the thesis work. It talks about the WSN issue that is implemented in the work.

Chapter 4 explains all about algorithms and various steps involved in generating our graph and representing the coverage issue.

Chapter 5 shows the graphs obtained in support of our work. The graph is plotted by taking the number of nodes that satisfy the problem statement on y-axis and total number of nodes that are being deployed on x-axis.

Chapter 6 finally concludes how the work done so far can be extended further.

## **1.5 Summary**

In this chapter a brief introduction of WSN was given. The major objectives and motives were highlighted.

# Chapter 2

## Background

*Introduction*

*Traditional Sensing Method*

*Current Sensing Method*

*Applications of WSN*

*Challenges of WSN*

*Features affecting design of WSN*

*Sensor node*

*Summary*

## 2.1 Introduction

In this chapter we are briefly reviewing the history, advancement and features of WSN. A WSN consists of spatially distributed autonomous sensors those cooperatively monitor the physical or environmental conditions including temperature, sound, vibration, motion, pressure or pollutants. In sensor networks where the environment is needed to be remotely monitored, the data from the individual sensor nodes is sent to a central base station (often located far from the network), through which the end-user can access data[5].

This chapter is organized as follows. Section 2.1 and 2.2 deal with Traditional and Current sensing Methods. Section 2.3 states various applications of WSN. Section 2.4 enlists the challenges in field of WSN. Section 2.5 lists out essential features in designing a WSN. Section 2.6 describes the architecture of a sensor node.

## 2.2 Traditional Sensing Method

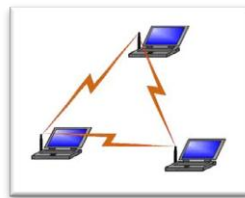


Figure 2.1 sensing method earlier  
adapted from [16]

- Sensors are close to objects.
- Sensors only generate data streams.
- Sensors do not have computation ability.
- Sensors do not communicate.



## 2.3 Current Sensing Method

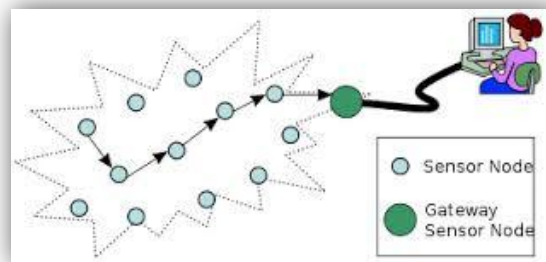


Figure 2.2 current sensing method  
adapted from [16]

- A sensor network covers a sensing area.
- Each sensor is responsible for the object nearby.
- Sensors cooperate to complete the sensing task.
- Multi-hop routing is employed to report the sensed data to users.

## 2.4 Applications of WSN

- *Military applications*

Utilized as a part of checking amicable powers, supplies, and ammo; front line observation; surveillance of contradicting strengths and landscape; focusing on; fight harm evaluation and discovery of atomic, biotic, and concoction assaults.

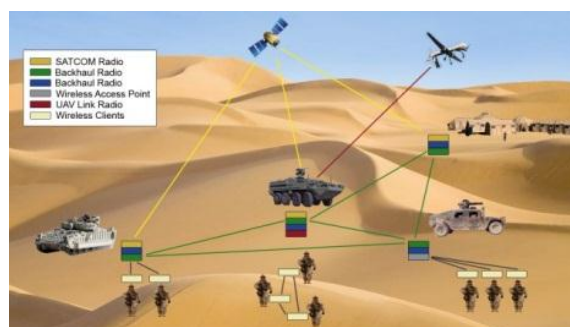


Figure 2.3 battlefield surveillance  
adapted from [16]

- *Environmental applications*

This includes forest fire detection, flood detection, in agriculture and in controlling air and water pollution.



Figure 2.4 environmental monitoring  
adapted from [16]

- *Health applications*

Like medication organization in clinics and following and checking specialists and patients inside a clinic.



Figure 2.5 health monitoring  
adapted from [16]

- *Other commercial applications which are quite helpful in remote monitoring and technical inspection*
  - i) environmental control in office building
  - ii) interactive display centres
  - iii) inventory control in warehouses
  - iv) vehicle following and security



Figure 2.6 traffic monitoring  
adapted from [16]

## 2.5 Challenges of WSN

Limited battery power: Each sensor node has very limited power making it prone to lack of power, so saving energy, balancing energy consumptions, and maximising network lifetime is a challenge in this regard.

Limited computational ability: designing efficient distributed algorithms for a large number of sensors that have limited computation abilities in wireless distributed environment is not easy as sensors have embedded processors, memories and computational abilities.

Limited communication ability: completing transmission, query, analyse and mine sensed data with limited communication ability as transmission is only from several hundred metres.

Selection of transmission routes: since most sensors transmit information to a single destination so we need to use multi-hop communication methods.

Huge number of sensors and a big deployment region: making them robust and fault tolerance in both software and hardware, is challenging.

Sensor deployment: The expansive number of hubs expected in sensor system organizations and erratic nature of sending conditions present critical versatility and dependability concerns.

Coverage problem: In WSN every node has a locating run and observed zone must be sensed through the systems. So as to make the assets more proficient and drag out system lifetime, calculations that guarantee the checked district is completely secured is required. That is called as coverage issue.

Topology control: is a procedure utilized as a part of appropriated processing to change the underlying system to decrease the expense of disseminated calculations if run over the new coming about charts. The main issues being setting up the network area and its maintenance.

Localization: Since sensor systems may be sent in distant territories or fiasco alleviation operations , the position of sensor nodes may not be decided. Subsequently, a confinement framework is needed to give position data to the nodes. These variables incorporate the recognizable proof and connection of assembled information, node tending to, administration and question of nodes restricted in a decided locale, assessment of nodes' thickness and scope, vitality map era, geographic steering, article following, and other geographic calculations. These components make restriction frameworks a key innovation for the advancement and operation of WSNs.

Synchronization: The synchronization problem consists of four parts: send time, access time, propagation time, and receive time. Noise adds to intricacy in synchronization bringing about flawed time. Also the error of the time itself, there are issues connected with clock skew that assume more unpredictability in a conveyed framework in which a few workstations will need to understand the same worldwide time[3].

Signal processing: a sensor node combines the abilities to compute, communicate and sense. Ecological obstruction and multi-way blurring acquaint estimation failures with just about all current going advances. The level of blunders nature-subordinate.

In cruel networking situations, the blunders might be high that makes extending methods incapable.

## 2.6 Features affecting design of WSN

- Fault tolerance
- Scalability to large scale deployment
- Production costs
- Hardware constraints
- Sensor network topology
- Environmental conditions
- Medium for transmission
- Power Consumption in sensing, communication and processing data.

## 2.7 Sensor node

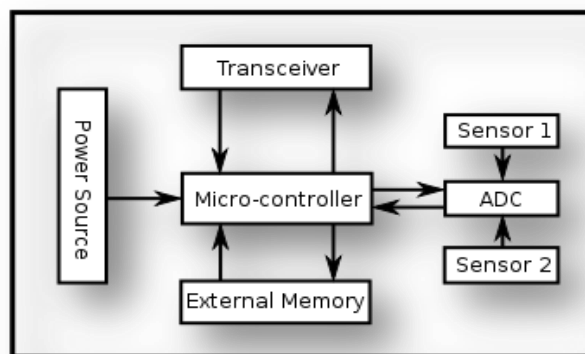


Figure 2.7 Architecture of a sensor node(adapted from [16])

- A sensor node is a node in a WSN that is equipped for performing some handling, get-together tangible data and speaking with other associated nodes in the network.

- The main components of a sensor node include a transceiver, external memory, microcontroller, power source with a combination of one or more sensors.
- The controller performs various functions, forms information and controls the usefulness of different segments in the sensor node. The most common one being microcontroller.
- sensor nodes regularly make utilization of ISM band, which gives free radio, range portion and worldwide accessibility. The conceivable decisions of remote transmission media are radio recurrence (RF), optical correspondence (laser) and infrared.
- the most significant sorts of memory are the on-chip memory of a microcontroller and Flash memory—off-chip RAM is seldom utilized.
- the sensor node expends power for sensing, conveying and information transforming. Sensors are fittings gadgets that prepare a measurable reaction to a change in a physical condition like temperature or weight. Sensors measure physical information of the parameter to be monitored.

## 2.8 Summary

In this chapter WSN was elaborated. The issues of WSN that can be worked upon was listed. Its various applications were stated. Features to be kept in mind while designing such a network and architecture of a sensor node has been described.

# Chapter 3

## *Coverage problem*

*Introduction*

*Coverage Problem*

*Static Coverage Problem*

*Dynamic Coverage*

*Summary*

# Chapter 3

## 3.1 Introduction

Sensor systems are an auspicious coming in various provisions, for example, supervision of security and wellbeing of structures, galleries, movement control and in checking ecological contaminations. The fast advancement of registering gadgets emphasizing remote innovations impacts our ordinary life. With the ubiquity of laptops, cells, PDAs, GPS gadgets, and wise hardware in the post-PC period, registering gadgets have gotten to be less expensive, more portable, more appropriated, and more pervasive in day by day life[5]. The development of remote sensor systems (WSNs) is basically the most recent pattern of Moore's Law at the scaling down and universality of registering gadgets. Normally, a remote sensor node (or essentially sensor node) comprises of sensing, processing, correspondence, incitation, and force parts.

A remote sensor system (WSN) comprises of spatially dispersed self-sufficient sensors to screen physical or natural conditions, for example, temperature, sound, vibration, pressure, movement or poisons and to helpfully pass their information through the system to a fundamental area[2]. The more cutting edge systems are bi-directional, additionally empowering control of sensor movement. Today such systems are utilized as a part of numerous modern and customer requisitions, for example, mechanical procedure observing and control, machine wellbeing checking, etc. Today, this environment is joined together with the novel and impromptu systems administration engineering to encourage between-sensor correspondence. The adaptability of introducing and arranging a sensor is in this way extraordinarily made strides.

Since large number of sensors maybe deployed in any arbitrary manner, one of the fundamental issues in a wireless sensor network is **the coverage problem**. Under specific presumptions a signal(acoustic or light) might be caught with certain base indicator to noise proportion by a sensor node if the sensor is inside a certain base sign source, and that every node can screen a disk(the range of which is known as



the discovering extent of the sensor node) focused at the node on a 2D surface. The coverage issue might be depicted as takes after:

- minimum number of sensor nodes required to monitor the area.
- proper distribution keeping in mind the energy constraint.

## 3.2 Coverage problem

A coverage problem can be classified as:

- (1) Static coverage problem[5]: accepting that identifying reach is a disk with range  $r$  in 2D, what is the base situated of nodes that must be obliged to cover the whole territory. Recognizing the cover around the sensor nodes, what is the scope calculation that can guarantee the covers around the sensors be the most modest while coating the entire observed range.
- (2) Dynamic accommodation: different areas have different required percentage of monitoring so the number of nodes actively working should correspond to the needs; which might include shutting down some nodes when the precision exceeds the demand and vice-versa and secondly, reduce power consumption. Another approach can be putting the sensor node in active or sleep mode; where we can use a term duty time, a ration to active time to sleep time.

In the work ahead the static coverage problem is dealt and discussed.

Checking provisions characterize an essential class of requisitions utilized within remote sensor systems[1]. In these provisions the system sees nature's domain and scans for occasion events (phenomena) by sensing diverse physical properties, for example, temperature, stickiness, weight, encompassing light, development, and vicinity (for target following). In such cases the area data of both phenomena and nodes is typically needed for following and association purposes. In this work we abridge a large portion of the ideas identified with restriction frameworks for WSNs and also how to confine the nodes in these systems (which permits the limitation of phenomena). By partitioning the confinement frameworks into three unique segments —

separation(distance)/angle estimation, position reckoning, and restriction algorithm — other than giving an educational perspective, we indicate that these parts could be seen as subareas of the limitation issue that need to be investigated and contemplated independently.

### **3.3 Static coverage problem**

The coverage problem reflects how well an area is tracked by sensors[7]. The inspiration of examination on the scope of sensor systems is to insurance that the checked region might be caught by the systems. As a rule sensors gather information from nature's domain without any varieties. Under the presumption that the building design of remote sensor system does not change with the system advancement, various scope calculations have been proposed as per introductory undertaking duty and necessities. This scope issue is static one. The trouble in this issue is the meaning of catching extent and its impact on the whole system. The investment is to completely blanket the observed territory with the minimum number of sensor nodes. It can likewise be expressed as creating a sensor dispersion calculation to make the introduction territory (where the sensor node can't locate) be the slightest or to minimize the covered sensing region of sensor nodes.

Now there exists a closed relationship between the static coverage problem and the art gallery problem(hence referred to as AGP)[7]. The AGP is to determine the minimum number of guards required to cover any point in the inside of the gallery at any given instant of time. Linking the AGP with the coverage scenario, the algorithm can be solved optimally in 2D space while described as NP-hard in the three dimensional space. However, accurate coverage solutions can only be used in the regular and small monitoring areas. For larger irregular areas, another scheme with a different optimization approach would be used. A coverage uniformity is considered in the network to obtain more robust coverage. A sensor node serves as a source of force for rest of its neighbouring sensors and this approach does monitor the area completely[10].

## 3.4 Dynamic Coverage

Alberto's approach divides the network region into groups of many small nodes with header in each group. This header holds the responsibility of detecting the moving objects. The nodes can turn off or on depending on the transformed space. When an object is detected by any header, it wakes up the surrounding/neighbouring sensor nodes that have their detecting range around that object. As the object moves out of any detecting radius, the corresponding node goes to the sleep mode[9][10]. Such a network also aims at turning off redundant nodes. That is to say, if the same region is being sensed by many sensors, it turns off some sensors as a means to conserve energy and enhance the lifetime of the wireless sensor network. A coverage preserving node scheduling policy is followed to determine at what instant or for what instant of time a/more nodes will be kept in sleep mode.

## 3.5 Summary

In this chapter we explained what is a coverage problem. We then highlighted how a coverage issue can be classified. We then moved onto to describing Static Coverage Problem and Dynamic Coverage.

# Chapter 4

*Implementation of coverage problem*

*Introduction*

*Network Model*

*Algorithm for k-UC problem*

*Algorithm for k-NC problem*

*Summary*

# Chapter 4

## Implementation of coverage problem

### 4.1 Introduction

In this chapter we are going to deal with implementation part of our thesis, where we state the assumptions, work flow, input, output.

Section 4.2 describes the network model of our work. Section 4.3 gives the algorithm for evaluating the coverage problem when the sensing radii of the sensor nodes of our network are same. Section 4.4 describes the coverage problem when we deploy sensors with different sensing radii.

### 4.2 Network Model

A wireless sensor system comprises of  $N$  number of sensors conveyed self-assertively in a region. One of the key issues here is the COVERAGE PROBLEM. It reflects how well a territory is, no doubt observed by sensors.

So in our work we generalize this problem.

Given a set of sensors  $\{n_1, n_2, n_3, \dots, n_n\}$  deployed in an area in arbitrary manner.

We have to determine if the area is  $k$ -covered or not. That is to say that, each point in the area is at least covered by 'k' sensors or not. 'k' is a pre-defined constant[6][12].

The sensing region of each sensor can be →Unit disk

→Non-unit disk

Instead of deciding the scope of every area, we divide our area into perimeters of each sensor and how is this perimeter of sensing range covered.

As long as the perimeters are k-covered, the entire zone is k-covered.

### **The k-UC problem**

- The radii of sensitivity of all sensors is equal to a constant  $r$ [4, 7].

### **The k-NC problem**

- The sensors are heterogeneous as they have different sensing ranges[7].
- For computations further we consider two sensors  $s_i$  and  $s_j$  where  $s_j$  is to the west of  $s_i$  with sensing radii as  $r_j$  and  $r_i$  respectively.

## **4.3 Algorithm for k-UC problem**

Input: File containing x and y-coordinates of n number of sensors to be deployed in 2D space.

Output: graph with those n number of sensor nodes scattered in 2D space.

1. Set up a two-dimensional area A with 'n' sensors  $\{s_1, s_2, s_3, \dots, s_n\}$ , where each sensor  $s_i$  is located at  $(x_i, y_i)$  in A.

2. Sensing range  $r = \text{constant}$  (0.6)

3. For each node do

Calculate the Euclidean distance  $d(s_i, s_j)$  between a pair of sensors  $s_i$  and  $s_j$ .

If  $d(s_i, s_j) > 2r$

then

$s_j$  does not add-up to the perimeter coverage of  $s_i$

else

(a) angle  $\alpha = \cos^{-1}[d(s_i, s_j)/(2r)]$

(b)  $\alpha_L = \pi - \alpha$

$$\alpha_R = \pi + \alpha$$

(c) get this perimeter covered (in radians) as:  $2\pi r \times (2\alpha/360)$

And get the maximum perimeter among all 'j' neighbours of this  $i^{\text{th}}$  node.

4. Repeat 3 for all other sensors.
5. Define the constant k, which denotes k-covered.
6. Store the sensor number and its corresponding no. of neighbours in a file neighbor.txt
7. Plot a graph verses k-coverage and no. of nodes experimented with.
8. Vary r and repeat from steps 2 to 7.
9. End

## 4.4 Algorithm for k-NC problem

Input: File containing n number of sensors' x and y- coordinates along with radius of connectivity of each sensor perimeter.

Output: graph is generated that scatters those n number of nodes in 2D area.

1. Set up a two-dimensional area A with 'n' sensors  $\{s_1, s_2, s_3, \dots, s_n\}$ , where each sensor  $s_i$  is located at  $(x_i, y_i)$  in a 2D area A.
2. Sensing range of each sensor is unit disk, i.e.  $r_1, r_2, \dots, r_n$  where  $r_1 \neq r_2 \neq \dots \neq r_n$ .
3. For each pair of nodes, do

4. Calculate the Euclidean distance  $d(s_i, s_j)$ .
5. If  $s_j$  is outside  $s_i$ ,  $d(s_j, s_i) > r_i$
6. if  $d(s_i, s_j) - r_i > r_j$ , then  $s_i$  covered by  $s_j$ .
7. If  $d(s_i, s_j) - r_i < r_j < d(s_i, s_j) + r_i$ , then arc of  $s_i$  falling in  $s_j$  is perimeter covered.
8.  $\cos \alpha = (r_i^2 + d(s_i, s_j)^2 - r_j^2) / (2 * r_i * d(s_i, s_j))$
9. If  $r_j > d(s_i, s_j) + r_i$ , then  $s_i$  is fully covered by  $s_j$ .
10. If  $s_j$  is inside  $s_i$ ,  $d(s_i, s_j) \leq r_i$ .
11. If  $r_i - d(s_i, s_j) > r_j$ , then  $s_i$  is not covered by  $s_j$ .
12. If  $d(s_i, s_j) + r_i < r_j < d(s_i, s_j) + r_i$ , then arc of  $s_i$  falling in  $s_j$  is perimeter covered. The region is determined by formula as in step 8.
13. If  $r_j > d(s_i, s_j) + r_i$ , then  $s_i$  is fully covered by  $s_j$ .
14. End

## 4.5 Summary

In this chapter we explained about the algorithms of our results. We briefly explained the network model. We gave the equation to calculate the sensed region of a sensor by another sensor.



# Chapter 5

## *Performance Evaluation*

*Introduction*

*The k-UC problem*

*The k-NC problem*

*Summary*

# Chapter 5

## Performance evaluation

### 5.1 Introduction

The graphs ahead describe the results obtained when our code was executed. Section 5.2 gives the observations in case of a k-UC problem (the sensing radii of all sensors is same). Section 5.2 gives the observations for a k-NC problem. The results vary when any of the parameters, i.e. sensing radii( $r$ ) or k-covered(where  $k$  is a constant), is changed.

### 5.2 The k-UC problem

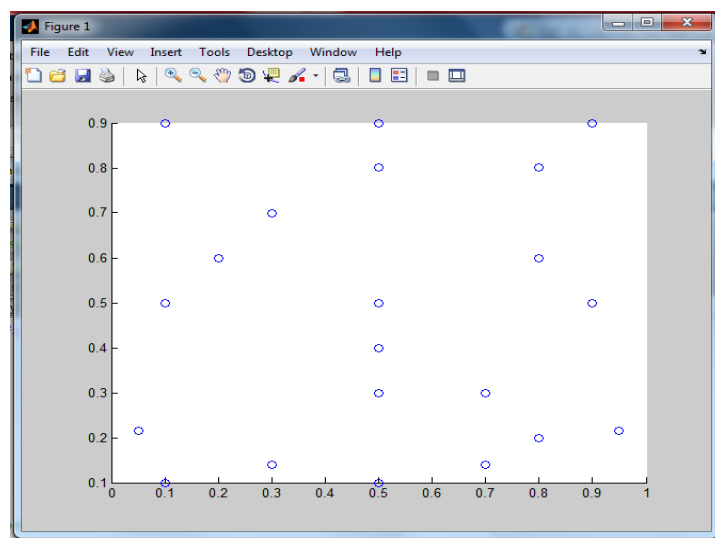


Figure: 5.1 Sensors deployed in an Euclidean plane

The figure shows some 'n' number of sensor nodes deployed in a two-dimensional space. This space depicts the area to be monitored.

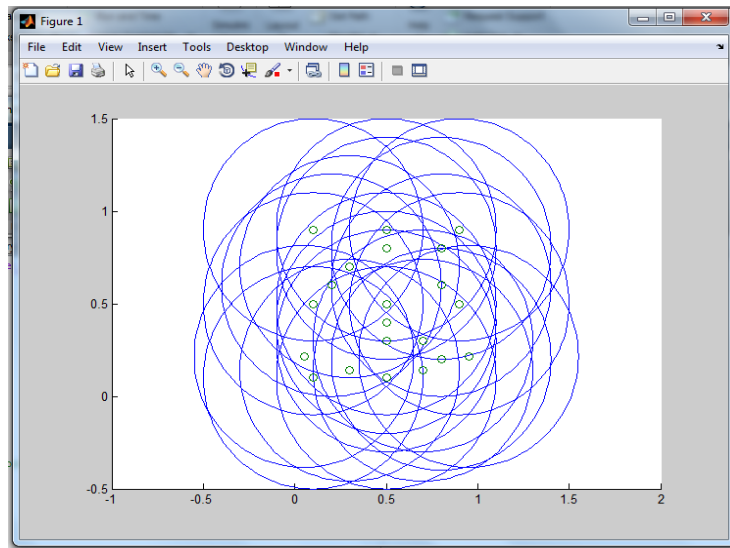


Figure: 5.2 sensors in Euclidean plane with sensing radii

The figure above shows 'n' number of sensors along with their sensing region. The circles generated depict the sensing range of corresponding sensors.

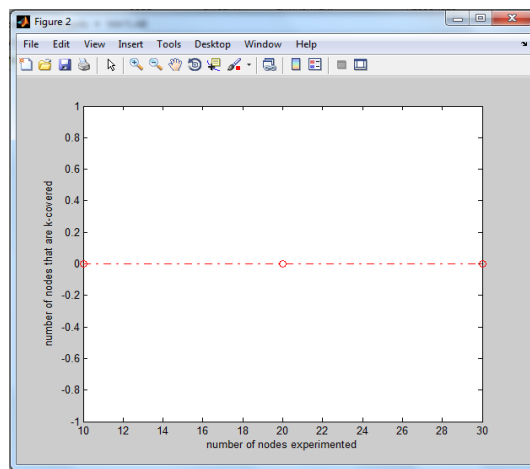


Figure: 5.3 no. of nodes k-covered vs total no. of nodes experimented for  $r=0.1$

The graph generated describes the scenario when the sensing range of a sensor is 0.1 unit. Number of sensor nodes that are deployed is taken on x-axis and the number of sensor nodes that are at least k-covered is taken on y-axis.

It is found that when sensing range is 0.1 unit none of the sensor nodes is sensed by any other sensor node.

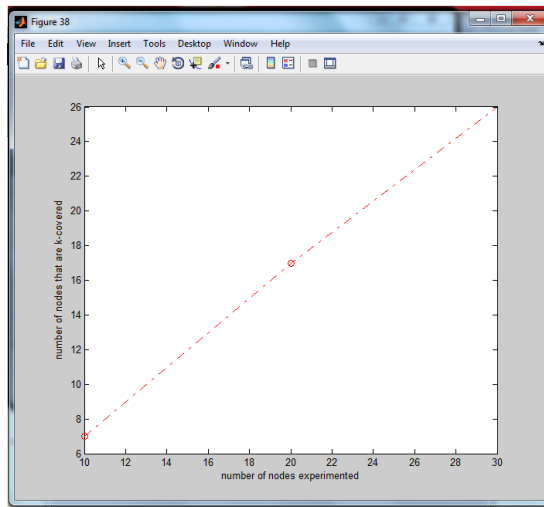


Figure: 5.4 no. of nodes k-covered vs total no. of nodes experimented for  $r=0.6$

The graph generated describes the scenario when the sensing range of a sensor is 0.6 unit. Number of sensor nodes that are deployed is taken on x-axis and the number of sensor nodes that are at least k-covered is taken on y-axis.

It is found that when sensing range is 0.6 unit 17 out of 20 sensor nodes are k-covered.

$$\text{slope} = 17/20 = 0.85$$

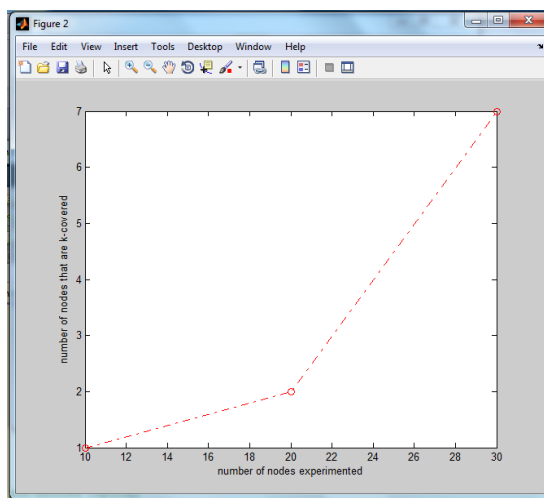


Figure: 5.5 no. of nodes k-covered vs total no. of nodes experimented for  $r=0.55$

The graph generated describes the scenario when the sensing range of a sensor is 0.55 unit. Number of sensor nodes that are deployed is taken on x-axis and the number of sensor nodes that are at least k-covered is taken on y-axis.

It is found that when sensing range is 0.55 unit 2 out of 20 sensor nodes are k-covered.

$$\text{slope} = 2/20 = 0.1$$

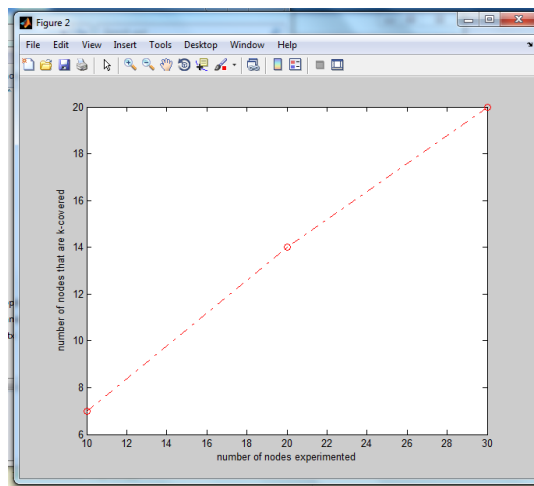


Figure: 5.6 no. of nodes k-covered vs total no. of nodes experimented for  $r=0.59$

The graph generated describes the scenario when the sensing range of a sensor is 0.59 unit. Number of sensor nodes that are deployed is taken on x-axis and the number of sensor nodes that are at least k-covered is taken on y-axis.

It is found that when sensing range is 0.59 unit 14 out of 20 sensor nodes are k-covered.

$$\text{slope} = 14/20 = 0.7$$

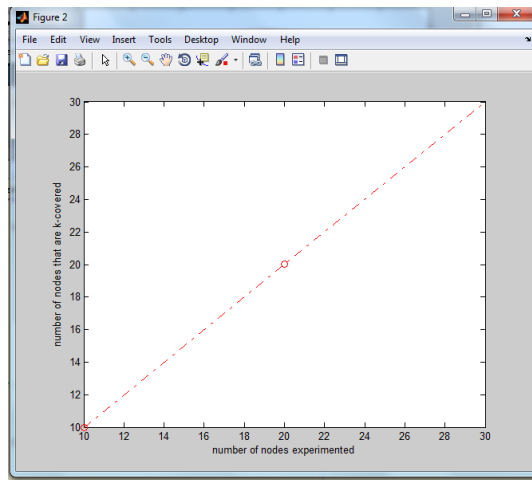


Figure: 5.7 no. of nodes k-covered vs total no. of nodes experimented for  $r=0.65$

The graph generated describes the scenario when the sensing range of a sensor is 0.65 unit. Number of sensor nodes that are deployed is taken on x-axis and the number of sensor nodes that are at least k-covered is taken on y-axis.

It is found that when sensing range is 0.65 unit 20 out of 20 sensor nodes are k-covered.

$$\text{slope} = 20/20 = 1.0$$

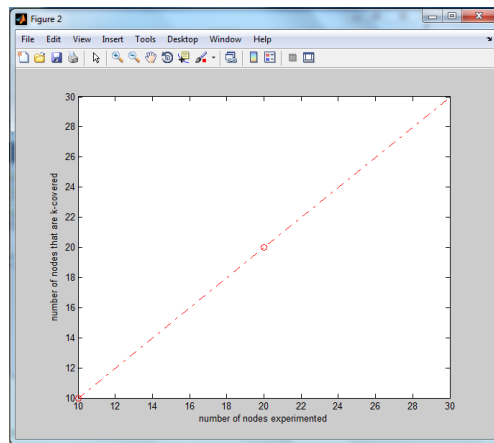


Figure: 5.8 no. of nodes k-covered vs total no. of nodes experimented for  $r=0.79$

The graph generated describes the scenario when the sensing range of a sensor is 0.79 unit. Number of sensor nodes that are deployed is taken on x-axis and the number of sensor nodes that are at least k-covered is taken on y-axis.

It is found that when sensing range is 0.79 unit 20 out of 20 sensor nodes are k-covered.

slope=  $20/20= 1.0$

## 5.3 The k-NC problem

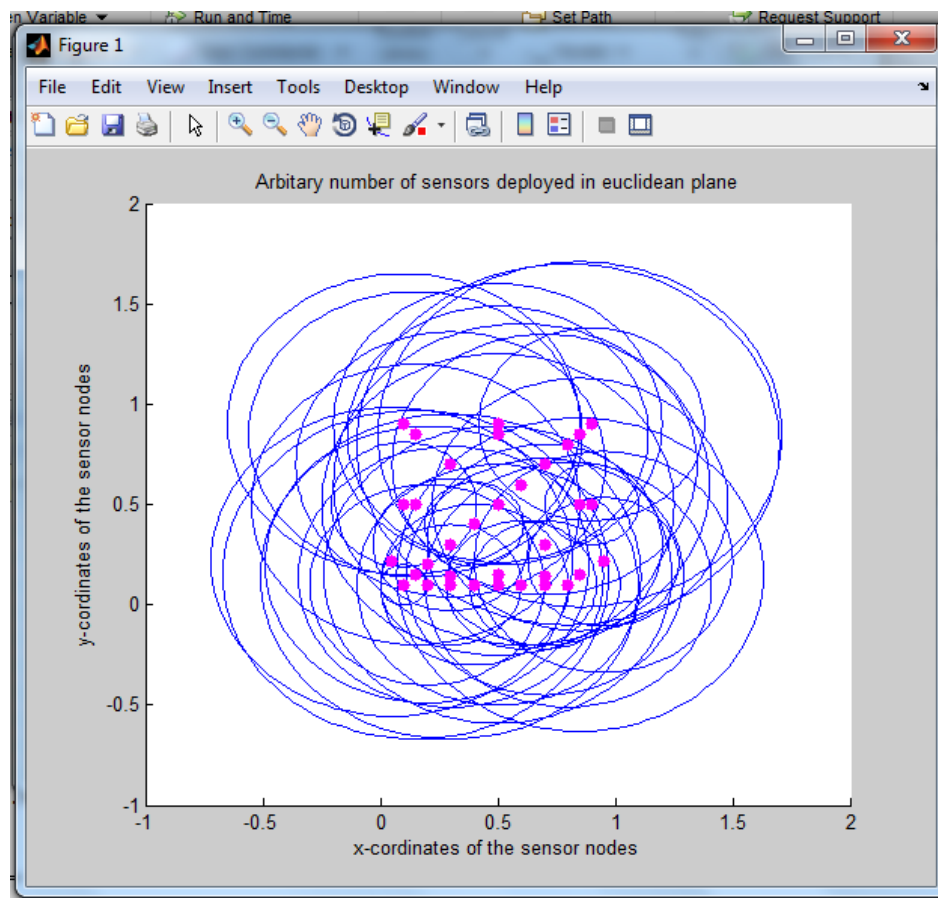


Figure 5.9 sensors with different sensing radii in Euclidean plane

The figure depicts some n number of sensors deployed in 2D area where the sensors have different sensing radii.

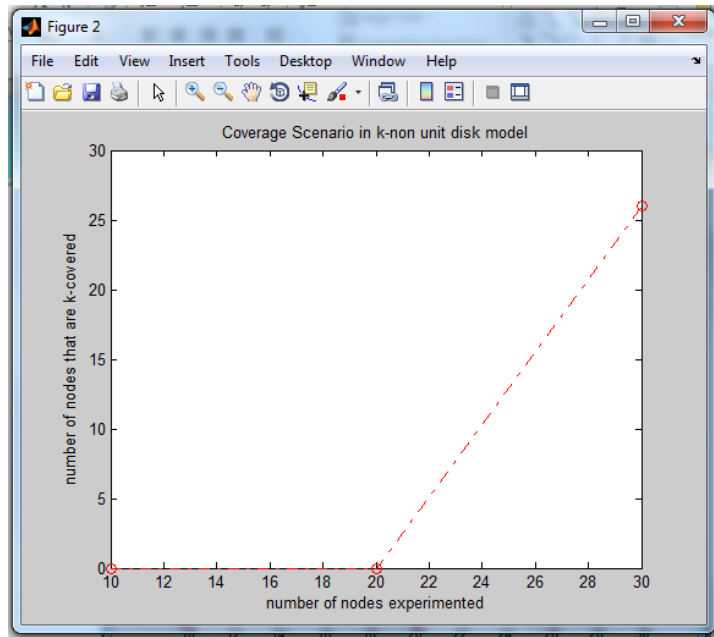


Figure 5.10 no. of nodes k-covered vs total no. of nodes experimented for  
 $k=5$

The figure above depicts the plot no. of nodes that are k-covered verses no. of nodes experimented with. The value of k here is taken as 5.

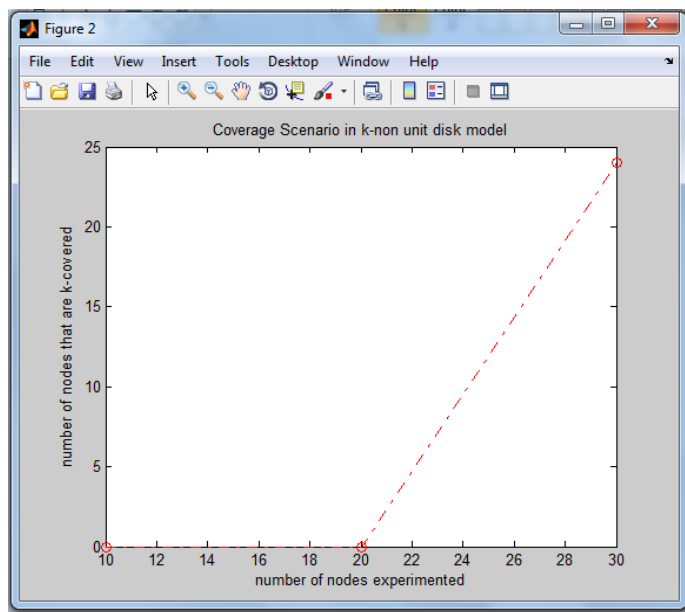


Figure 5.11 no. of nodes k-covered vs total no. of nodes experimented for  
 $k=10$



The figure above depicts the plot no. of nodes that are k-covered verses no. of nodes experimented with. The value of k here is taken as 10.

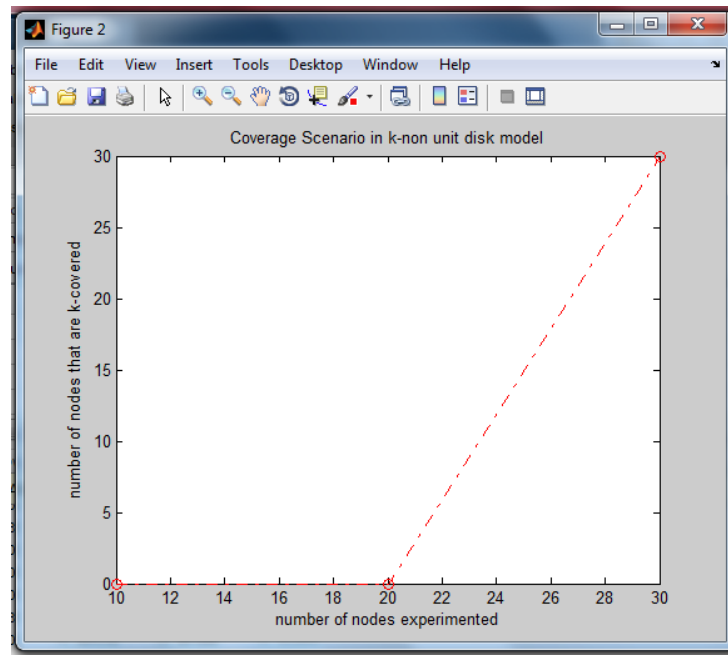


Figure 5.12 no. of nodes k-covered vs total no. of nodes experimented for  
 $k=2$

The figure above depicts the plot no. of nodes that are k-covered verses no. of nodes experimented with. The value of k here is taken as 2.

## 5.4 Summary

The results are analysed with the help of graphs. The coverage scenario varies on varying the parameters of sensing radii and k value. The next chapter concludes the thesis and discusses further scopes of improvement.

# Chapter 6

## *Conclusion and Future Work*

*Conclusion*

*Future work*

# Chapter 6

## Conclusion and Future work

### 6.1 Conclusions

WSNs possible today due to technological advancement in various domains. Envisioned to become an essential part of our lives as its quite helpful in remote sensing. Design Constraints need to be satisfied for realization of sensor networks. Tremendous research efforts being made in different layers of WSNs protocol stack. The coverage problem discussed here is successful in complete monitoring of a region. But the real world scenario includes the toroid space between sensors, which isn't included.

From our analysis we observe that when  $r= 0.65$  and  $r=0.79$ , the monitored region 100% k-covered.

### 6.2 Future work

The algorithm can be extended to include the 3D scenario of a sensor network. It can also be used in working for power reduction of a wireless sensor network and hence increase the lifetime of a network. The algorithm can be compiled to examine the results in case of hot spots.

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