Node Deployment and Coverage in Wireless Sensor Network

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Abstract—The Sensor Node deployment is a fundamental issue to be solved in Wireless Sensor Networks (WSNs). A proper node deployment scheme can reduce the complexity of problems in WSNs. Furthermore, it can extend the lifetime of WSNs by minimizing energy consumption. In this paper, we investigate random and deterministic sensor node deployments in WSN. Finally, We have taken a major performance evaluation measure namely coverage analysis for all the three sensor node deployment strategies.

Keywords—WSN (Wireless Sensor Network), SN (Sensor Node)

1. INTRODUCTION

Recent advancement, in WSN, we know in guided media the electromagnetic waves are guided through a solid medium, such as copper wire, coaxial cable or optical fiber etc likewise unguided media includes the atmosphere and the outer space which do not guide the waves, this form of transmission is referred to as wireless transmission. A wireless network is a type of network where no need of wire for connection of nodes. Here radio communication that is spread spectrum radio, infrared, cellular radio or satellite is used. No need to plug a cable into the computer to connect to the internet. Cell phone networks, Wi-Fi local networks etc are the examples of wireless network [1].

A WSN is a wireless network having sensors to sense physical or environmental conditions, like pressure, temperature, sound or pollutants of different places. A SN sense and react to events and phenomena in a specified environment, where the environment can be the physical world, a biological system, or an information technology framework. In other word it can be said that a WSN in an infrastructure consists of sensing (measuring), computing, and communication elements combines into a single tiny device through advanced mesh networking protocols. The mesh networking connectivity will seek out and exploit any possible communication path by hopping data from node in search of its destination. The power of wireless sensor networks lies in the ability to deploy large numbers of tiny nodes that assemble and configure themselves. The most important application of wireless sensor network technology is to monitor remote environments. For example, a chemical plant could be easily monitored for leaks by number of sensors which automatically form a wireless interconnection network and immediately report the detection of any chemical leaks. For installation of a SN, installer simply have to place a sensor at each sensing point. The network can be extended by simply adding more devices, no need of any rework or complex configuration is needed. For reducing the installation costs, WSN have the ability to dynamically adapt the changing environments that means it can respond to changes in network topologies and also it respond to different mode of operations. For example, the same network in a chemical factory can be used to localize the source of a leak and track the diffusion of poisonous gases. WSNs are not always homogeneous. In heterogeneous WSN some nodes of relatively higher energy are used to prolong the lifetime and reliability of WSNs. Thus the overall view of WSN shown in figure 2 and 3.

Applications of WSN

In[2] WSN applications can be classified into two categories: monitoring and tracking. Monitoring applications include indoor/outdoor environmental monitoring, health and wellness monitoring, power monitoring, inventory location monitoring, factory and process automation and structural monitoring. Tracking applications include tracking objects, animals, humans, and vehicles.
1. **Area monitoring**: Area monitoring is a common application of WSNs. In area monitoring, the WSN is deployed over a region where some phenomenon is to be monitored. A military example is the use of sensors to detect enemy intrusion; a civilian example is the geo-fencing of gas or oil pipelines.

2. **Environmental/Earth monitoring**: The WSNs are used in many ways to earth science research. This includes sensing volcanoes, oceans, glaciers, forests, etc. Some of the major areas are listed below.

3. **Air pollution monitoring**: The WSNs have been deployed in several cities to monitor the concentration of pollution in different areas. There are various architectures that can be used for such applications and also different kinds of data analysis is done.

4. **Forest fire detection**: Number of SNs can be deployed in a forest to detect when a fire has started. The nodes can be equipped with sensors to measure temperature, humidity and gases which are produced by fire in the trees or vegetation. The early detection is very much useful for a successful action of the firefighters. Only due to WSNs, the fire brigade will be able to know when a fire is started and how it is spreading.

5. **Landslide detection**: A landslide detection system makes use of a WSN to detect the slight movements of soil and changes in various parameters that may occur before or during a landslide. By using those data, it may be possible to know the occurrence of landslides long before it actually happens.

6. **Water quality monitoring**: Water quality monitoring means analyzing water properties in dams, rivers, lakes & oceans, as well as underground water reserves. By using many wireless distributed sensors water quality can be detected at any place easily.

7. **Natural disaster prevention**: The WSNs can effectively act to prevent the consequences of natural disasters, like floods. Wireless nodes have successfully been deployed in rivers where changes of the water levels have to be monitored in real time.

8. **Industrial monitoring**:
   a. **Machine health monitoring**: WSNs have been developed for machinery condition-based maintenance as they offer significant cost savings and enable new functionalities. Inaccessible locations, rotating machinery, hazardous or restricted areas, and mobile assets can be monitored with wireless sensors.
   b. **Data logging**: Wireless sensor networks are also used for the collection of data for monitoring of environmental information, this can be as simple as the monitoring of the temperature in a fridge to the level of water in overflow tanks in nuclear power plants. The collected information can then be used to show how systems are working.
   c. **Industrial sense and control application**: In research number of WSN communication protocols have been developed. While previous research was primarily focused on power awareness, more recent research have begun to consider some other aspects, such as wireless link reliability, real-time capabilities, or quality-of-service which are considered as an enabler for future applications in industrial and related wireless sense and control applications.
d. Greenhouses: WSNs are also used to monitor the temperature and humidity levels inside commercial greenhouses. When the temperature and humidity drops below specific levels, the greenhouse manager must be notified via e-mail or cell phone text message [3].

II. NODE DEPLOYMENT

What is deployment: The Deployment is the process of setting up a new computer or system in a place where it is ready for doing productive work in a real environment. In other word deploy can be define as doing productive work in a real environment. In other word deploy can be define as deploying a system in a real environment. In this scenario, the nodes have to discover their neighbours by themselves. If N nodes are uniformly distributed over an area A, the node density can be given by \( \lambda = N/A \). The probability that there are m nodes within the area S is Poisson distributed and can be given by

Where, \( e \) is the base of the natural logarithm (\( e = 2.71828... \)), \( k \) is the number of occurrences of an event - the probability of which is given by the function, \( \lambda \) is a positive real number, equal to the expected number of occurrences that occur during the given interval. For example, if the events occur on average every 5 minutes, and you are interested in the number of events occurring in a 20 minute interval, you would use a model as Poisson distribution with \( \lambda = 20/5 = 4.0 \). As a function of \( \lambda \), this is the probability mass function. The Poisson distribution can be derived as a limiting case of the binomial distribution. The Poisson distribution can be applied to systems with a large number of possible events, each of which is rare. Many other applications of Poisson noise have been developed, e.g., estimating the node density of uniformly distributed over an area.

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one sensor at each grid point, which is shown in figure 5. The approximate length of a unit square $d'$, which is equal to sensing radius $R_{s\text{sence}}$, can be calculated as follows:

First, the approximate area of a unit square with length $d'$ can be computed by dividing the whole area of a given field having radius $r$, with the number of cells, $k$. We do not know the value of $k$, but it is approximately equal to $(\sqrt{k} - 1)^2$ for the square grid. Since in the above figure for $k=4$, we get $n=9$ and for $k=9$, we get $n=16$. Here for one grid area $R_{s\text{sence}}^2 = k \times R_{\text{s\text{sence}}}^2$ which should be equal to the total area to be deployed.

A. For Circular Field: Overall View of square grid deployment for circular field is shown in figure 5.

If the deployed area is a circle, having radius $r$, then its area is equal to $\pi r^2$. So we can write the equation as follows:

$$ k \times R_{\text{s\text{sence}}}^2 = \pi r^2 $$

so we can write this equation as follows:

$$ R_{\text{s\text{sence}}}^2 = \sqrt{\frac{\pi r^2}{k}} $$

Where, $k$ = Number of grids $= (\sqrt{k} - 1)^2$ So we can write this.

Tri-Hexagon Tiling (THT)
The third strategy is based on tiling. A tiling is the covering of the entire plane with shapes which do not overlap nor leave any gaps. Tilings are also sometimes called tesselations. In tiling every vertex uses the same set of regular polygons. A regular polygon has the same side lengths and interior angles. Here we consider a semi-regular tiling that uses triangle and hexagon in the two dimensional plane, so-called 3-6-3-6 Tri-Hexagon Tiling. The name comes from going around a vertex and listing the number of sides each regular polygon has. Now we have to find out $R_{\text{s\text{sence}}}$ as follows:

<table>
<thead>
<tr>
<th>Name of area</th>
<th>Sides</th>
<th>Calculation of area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hexagon</td>
<td>r</td>
<td>$A_H = \frac{3\sqrt{3}}{2} r^2$</td>
</tr>
<tr>
<td>i.Circular Shaped Field</td>
<td>r</td>
<td>$R_{\text{s\text{sence}}} = \sqrt{\frac{4r^2}{3\sqrt{3}(\sqrt{3}/3 - 1)}}$</td>
</tr>
<tr>
<td>ii.Square Shaped Field</td>
<td>a</td>
<td>$R_{\text{s\text{sence}}} = \frac{4a^2}{3\sqrt{3}(\sqrt{2}/3 - 1)}$</td>
</tr>
<tr>
<td>iii.Rectangle Shaped Field</td>
<td>a, b</td>
<td>$R_{\text{s\text{sence}}} = \frac{4(ab)}{3\sqrt{3}(\sqrt{2}/3 - 1)}$</td>
</tr>
<tr>
<td>Octagon</td>
<td>r</td>
<td>$2R_{\text{s\text{sence}}}^2 (1 + \sqrt{2})$</td>
</tr>
<tr>
<td>i.Circular Shaped Field</td>
<td>r</td>
<td>$R_{\text{s\text{sence}}} = \sqrt{\frac{r^2}{(\sqrt{2}/2 - 2)^2 \times 2(1 + \sqrt{2})}}$</td>
</tr>
<tr>
<td>ii.Square Shaped Field</td>
<td>a</td>
<td>$R_{\text{s\text{sence}}} = \frac{a^2}{(\sqrt{2}/2 - 1)^2 \times 2(1 + \sqrt{2})}$</td>
</tr>
<tr>
<td>iii.Rectangle Shaped Field</td>
<td>a, b</td>
<td>$R_{\text{s\text{sence}}} = \frac{a \times b}{(\sqrt{2}/2 - 1)^2 \times 2(1 + \sqrt{2})}$</td>
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III. PERFORMANCE METRICS

In [6], there discussed the following performance metrics.

1. Coverage: In WSNs, the simple reason for checking coverage is to provide the high quality of information in the region of interest. This is also known as the area coverage which is important for most WSN applications. A full coverage and a partial coverage are both considered for WSN applications. To satisfy the full coverage of a given region of interest, every point in it must be covered by at least one sensor without allowing any uncovered points. However, there may be exceptions when the partial coverage can be assumed as the full coverage. For example, temperature or pressure sensing in environmental monitoring applications, where reading at one point is adequate for a region since it may have the same readings in its surrounding area. In any case, the overall coverage pretty much depends on both the sensing ranges and the deployment scheme of the nodes. To fulfill the desired coverage of a region, adjusting the sensing range has its limitations due to the expensive energy consumption and restricted node capabilities. Therefore, node deployment becomes very important. K-coverage is the usual way of specifying conditions on coverage.

2. K-coverage: In literature, k-coverage refers to the minimum k-coverage. A network is said to have k-coverage if every point in it is covered by at least k sensors. Although minimum k-coverage is worthwhile for surveillance kind of applications, other kinds of coverage, such as an average k-coverage or the maximum k-coverage, may be more meaningful for other WSN applications. Moreover, it seems inappropriate to measure k-coverage for performance comparison due to its sole interest in the minimum coverage area of the network. For this purpose we investigate the relative frequency of the exactly k-covered points in node deployment strategies.

3. K-coverage Map: We introduce a k-coverage map, which is used to check all possible coverage areas and to analyze the relative frequency of exactly k-covered points. Using the idea of the k-coverage map we measure the quality of coverage performance of node deployment strategies. To avoid confusion with k-coverage, in the following, we also use the term “exact k-coverage” for the k-coverage map, which defines the total area of the field covered by k sensor nodes. We model the k-coverage map for square grid, THT, octagon-square based tilling, decagon-star based deployments. For a uniform random deployment, it can be achieved by applying systematic sampling over a given field. We make the following assumptions to model the k-coverage map:

- A disc-based sensing model is used for homogeneous nodes where each sensor has a maximum sensing range of rsense.
- The sensing range, rsense, is the same as the length of a unit cell. Therefore rsense is different for different deployment methods.
- A point is covered by a node if it lies either within a disc of sensing range, rsense, or exactly at circumference of a disc.
- No boundary conditions are considered for any type of deployment, which seems reasonable for large-scale WSN scenarios.

Octagon Square Tiling

Figure 6 shows the k-coverage map of all possible exactly k-covered points of a octagon-square tiling cell. In the square grid cell, nodes are placed at the corners and their sensing ranges intersections form a tessellation of the region. As it is assumed that the sensing range is equal to the length of a cell, a octagon-square tilling cell has exact 0-coverage, 1-coverage, 2-coverage and 3-coverage regions. For instance, the middle region i.e. red-region has exact 0-coverage, white-regions are exact 1-coverage, yellow-region has exact 2-coverage, blue-regions are exact 3-coverage respectively.
Octagon Square Tiling
Figure 7 shows the k-coverage map of all possible exactly k-covered points of a decagon-star tiling cell. In the square grid cell, nodes are placed at the corners and their sensing ranges intersections form a tessellation of the region. As it is assumed that the sensing range is equal to the length of a cell, a octagon-square trilling cell has exact 0-coverage, 1-coverage, 2-coverage and 3-coverage regions. For instance, the middle region i.e red-region has exact 0-coverage, white-regions are exact 1-coverage, yellow-region has exact 2-coverage, blue-regions are exact 3-coverage respectively.

IV. SIMULATION

Octagon Square Triling :

![Diagram](image-url)
V. CONCLUSIONS

The Wireless Sensor Network (WSN) can be composed of homogeneous or heterogeneous sensor nodes also termed as motes, which adapts the same or different coordination, sensing and computation abilities, respectively. The conclusion of this work points towards the node deployment pattern as a better option for Wireless Sensor Networks (WSN) in the sense of coverage performance evaluation, as its average coverage is better than the other strategies. It can also be seen that random deployment is not a bad strategy and it is comparable to the popular square grid deployment for the worst-case delay. Of course, we analyzed these metrics based on certain assumptions.

REFERENCES

[5] "DESIGN OF NODE AND ITS CLUSTERING STRUCTURE IN WIRELESS SENSOR NETWORKS” , Mr. Rajeeb Sankar Bal , Prof. (Dr.) Amiya Kumar Rath