Node Deployment Coverage in Large Wireless Sensor Networks

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Abstract – Currently, wireless sensor network (WSN) is being applied in a lot of different applications. To a large extent the effectiveness of the WSNs depends on the exposure provided by the sensor deployment proposal. There are different deployment demands in different environment. Firstly, we cover the existing deployment method of sensor nodes (SNs) in WSN. We investigate random and deterministic sensor node (SN) deployments for large-scale WSNs in the performance metric coverage. We consider three regular fields circle, rectangle and square for a uniform random, a square grid, a pattern-based Tri-Hexagon Tiling (THT) and Hexagon Tiling (HT) node deployment. Finally, we analyze tradeoffs between these performances metric for each deployment plan to show which approach is preferable under what factors, e.g., the number of SNs.

Index Terms – Wireless Sensor Network (WSN), Sensor Node(SN), Tri-Hexagon Tiling (THT), Hexagon Tilling(TH).

1. INTRODUCTION

A wireless sensor network can be defined as a wireless communication consisting of countless distributed devices using sensors to monitor physical or environmental conditions and also tracking objects shown in fig.1.

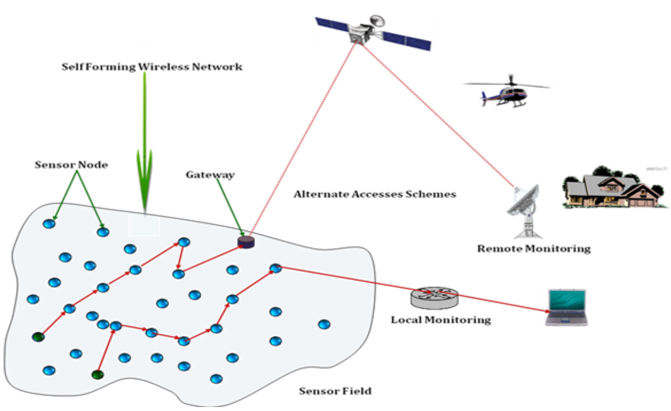

Fig. 1. The overall view of WSN.

It is capable to provide the information logged by the sensors to remote locations and it can do so without the use of a big and composite wired networks. The whole setup of data being sent from the sensors distributed across a wide area by means of the WSN is performed and defined as the WSN. Wireless network of sensors spread over an area. Such kind of networks is usually used for monitoring applications include indoor or outdoor and the tracking applications include tracking objects.

The WSN is built of “nodes” from a little to several hundreds or even thousands where each node is connected to one (or sometimes several) sensors. The data is forwarded probably via multiple hops to a sink (occasionally denoted as controller or monitor) that can use it locally or it is connected to new networks (e.g., the Internet) through a gateway. The nodes can be stationary or moving. They can be responsive of their position or not. They can be homogeneous or not [1] shown in fig. 2.

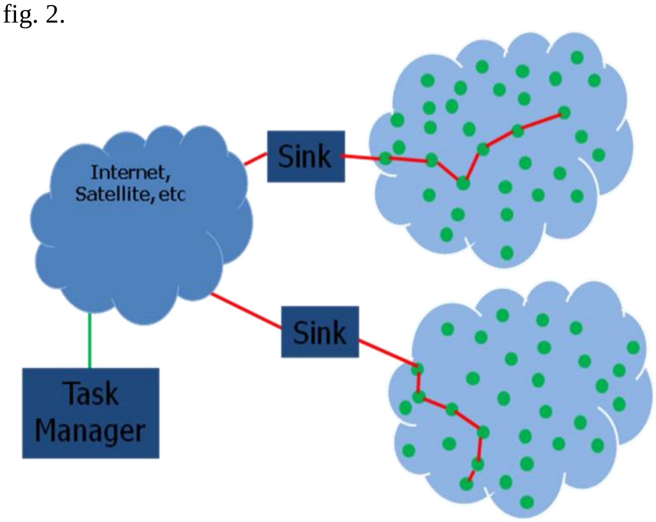

Fig. 2. The Overall view of WSN and its Architecture.

This is a traditional single-sink WSN shown in fig.2.The single-sink system suffers from the lack of scalability by increasing the number of nodes, the quantity of data gathered by the sink increases and once its ability is reached, the network size cannot be augmented. In addition, for reasons related to MAC and routing aspects, network performance cannot be measured independent from the network size shown in fig. 3.

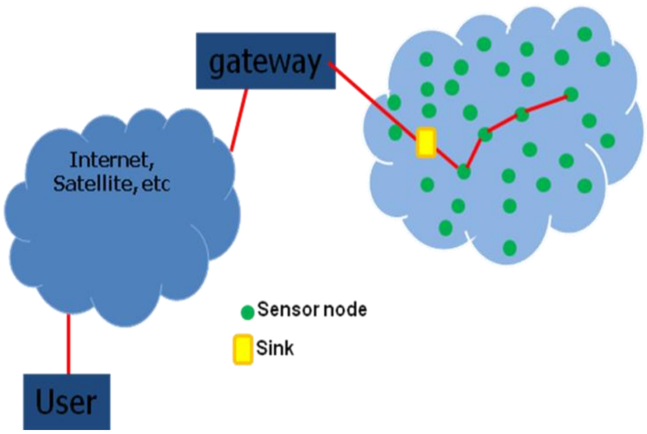

Fig. 3. The Single sink scenario in WSN.

A more general scenario includes multiple sinks in the network shown in fig.4. Given a level of node solidity, a larger number of sinks will decrease the possibility of isolated groups of nodes that cannot send their data due to unfortunate signal propagation conditions. In standard, a multiple-sink WSN can be scalable while this is evidently not true for a single sink network. Still, a multi-sink WSN does not represent an insignificant extension of a single sink container for the network trick. In numerous cases nodes send the data composed to one of the sinks chosen among many which forward the data to the gateway headed for the final user. From the protocol point of view means that a choice can be done based on a suitable criterion that could be least delay, greatest throughput, least number of hops, etc. Thus, the existence of multiple sinks ensures better network performance with respect to the single sink case, but the contact protocols must be more complex and should be designed according to appropriate criteria [2].

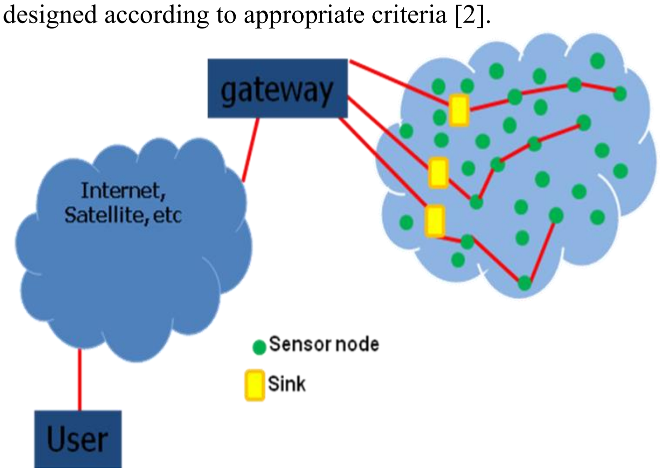

Fig. 4. The Multi sink scenario in WSN.

Lastly, the construction of WSNs may be categorized into three classes are as hardware, wireless networking, and applications.

1.1 Hardware of Sensor Node

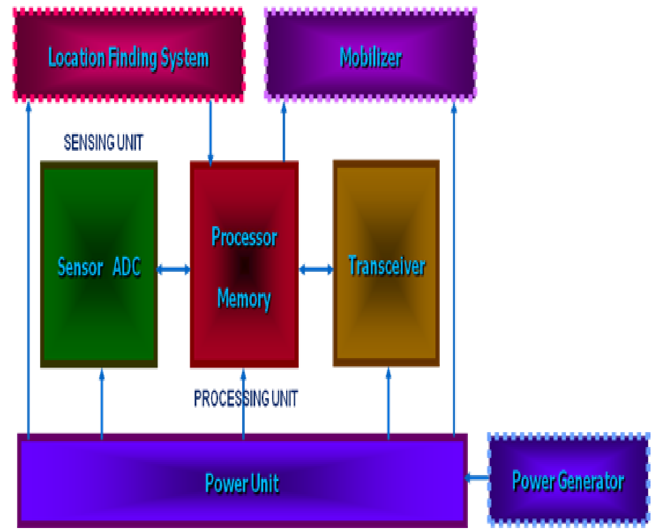

Fig. 5. The components of sensor node in wireless sensor network.

The general architecture and the major components of a wireless sensor device (node) are shown in fig. 5. Generally, a node is composed of four basic components: a sensing unit, a processing unit, a transceiver unit and a power unit. Moreover, additional components can also be integrated into the sensor node depending on the application. These components are in shown in fig. 5 include: a location finding system, a power generator, and a mobilizer.

- Sensing unit: The sensing unit is the main component of a sensor node that distinguishes it from any other embedded system with communication capabilities.
- Processing unit: The processing unit is the main controller of the wireless sensor node through which every other component is managed. The processing unit may consist of an on-board memory or may be associated with a small storage unit integrated into the embedded board.
- Transceiver unit: The communication between any two wireless sensor nodes is performed by the transceiver units.
- Power unit: One of the most important components of a wireless sensor node is the power unit. Usually, battery power is used, but other energy sources are also possible. Each component in the wireless sensor node is powered through the power unit and the limited capacity of this unit requires energy-efficient operation for the tasks performed by each component.
- Location finding system: Most of the WSN applications, sensing tasks, and routing techniques need knowledge of the physical location of a node. Thus, it is common for a sensor node to be equipped with a location finding system.

- Mobilizer: A mobilizer may sometimes be needed to move sensor nodes when it is necessary to carry out the assigned tasks. Mobility support requires extensive energy resources and should be provided efficiently.
- Power generator: While battery power is mostly used in sensor nodes, an additional power generator can be used for applications where longer network lifetime is essential. For outdoor applications, solar cells are used to generate power. Similarly, energy scavenging techniques for thermal, kinetic, and vibration energy can also be used [3].

1.2 Wireless networking

In [4]. a network management system designed for WSNs must take into account the unique properties of WSNs. The following criteria are used to estimate the WSN management systems:

- Lightweight operation. A system should be able to run on sensor nodes without consuming too much energy or interfering with the operation of the sensor nodes. Lightweight operation prolongs network lifetime.
- Robustness and fault tolerance. WSNs are prone to network dynamics such as dropped packets, nodes dying, becoming disconnected, powering on or off, and new nodes joining the network. A management system should be resilient to network dynamics by reconfiguring the network as required.
- Adaptability and responsiveness. A system should be able to retrieve and adapt to the current network states or changing network conditions including changes in network topology, node energy level, and the coverage and exposure bounds of WSNs.
- Minimal data storage. A data model used to represent management data must be extensible and able to accommodate information needed to perform the management functions, but must also respect the memory constraints of WSNs.
- Scalability. A system should operate efficiently in any network size.

1.3 WSN Applications

The recent advances in WSN, the applications can be classified into two categories: monitoring and tracking shown in fig.6. The *monitoring* applications include indoor/outdoor environmental monitoring, health and wellness monitoring, power monitoring, inventory location monitoring, factory and process automation, and seismic and structural monitoring. The *tracking* applications include tracking objects, animals, humans, and vehicles [5].

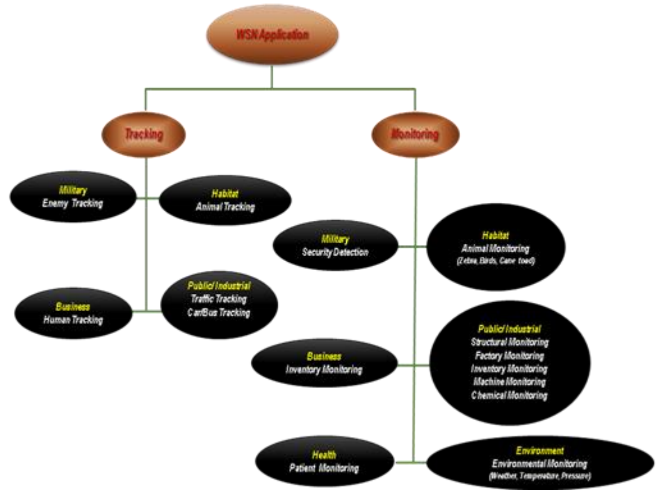

Fig. 6. The Applications of WSN.

2. NODE DEPLOYMENT

All the related works that have been done by other researchers that are related to the current research problem should be summarized in this section. Times New Roman font with size 10 must be used in this section. Sub topic should be written as

A Wireless Sensor Network (WSN) can be self-possessed of homogeneous or heterogeneous nodes, which possess the same or different communication and computation capabilities, respectively. Although some works consider heterogeneous nodes, a lot of existing works investigate node placement in the circumstance of homogeneous WSNs. Less complexity and a better manageability are the most valuable effects of homogeneity. Hence, we consider homogeneous nodes in WSNs. These nodes can be deployed over a network in random or deterministic manner. While the random node deployment is preferable in many applications, if possible, other deployments should be investigated since unfortunate node deployment can raise the complexity of other problems in WSNs.

2.1 Classification of Deployment

In WSN, the deployment of sensor nodes mainly concentrated in the static and the dynamic deployment.

In static deployment, according to the optimization strategy, it chooses the best location and the location of the sensor nodes has no change in the life span of the WSN. In current, this deployment includes the deterministic deployment and the randomly deployment. The self-organized algorithms are proposed by waking up some sensor nodes or making some sensor nodes sleep. This algorithm used the essential potential field to make the sensor nodes move positions and change directions automatically in detection area based on directional sensing model. With the conclusion of multiple prior coverage of hot targets which needed higher quality necessities, the algorithm could maximize the coverage rate throughout the detection area. As per Poisson distribution, also it proposed a strategy of WSN nodes randomly deployment. In this strategy, first established the model of WSN node distribution and find the relationship between the profit of coverage area and the nodes density of target area. Finally, find the best range of nodes density to get the optimal deployment [6].

In dynamic deployment, It may be backed to the deployment of the robot in WSN. In order to make the sensor networks get the most performance, sensor nodes need automatically shift to proper location, and then start to work. In the random deployment, namely randomly throw nodes firstly, and then using a selection of optimization algorithm for deployment optimization. Such as Virtual force algorithm, virtual force oriented particles algorithm, simulated annealing algorithm, particle swarm optimization algorithm and simulated annealing genetic algorithm [6].

2.2 Classifying Coverage Schemes

In [6], the development of energy efficient schemes integrating coverage and connectivity for WSN which depended on the coverage objectives and applications shown in fig. 7. In WSN, the coverage can be classified into three categories area coverage, point coverage, and path coverage.

Area coverage: In this coverage, the main objective of the sensor network is to cover (monitor) a region (the group of all space points within the sensor field), and each point of the region need to be monitored.

Point coverage: In this coverage, the objective is to cover a set of point (target) with known position that need to be monitored. Again in this coverage scheme, it focuses on determining sensor nodes exact positions where guarantee efficient coverage application for a limited number of immobile points (targets). Generally, it can be solved as a particular case of the area coverage problem when sensor nodes number may leave out of account.

Path coverage: In this coverage, the goal is to minimize or maximize the probability of undetected penetration through the region.

In brief, we introduce how to evaluate the coverage performance of a region covered by WSN. Given a set of sensors deployed in a monitored region, coverage-evaluating problem is to determine if all points in the region is suitably *k-covered*, in the sense that all point in the target area is enclosed by at least *k* sensors, where *k* is a given parameter.

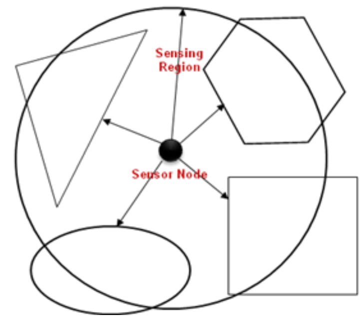

Fig. 7. The sensor node surround by non-penetrate obstacle.

2.2 K-Coverage

In [6], k-coverage refers to the minimum k-coverage. A network is said to have k-coverage if each point in it is covered by at least k sensors. As per [6] formulate k-coverage of the region for mostly sleeping large-scale WSNs. Also, it is claimed that the critical value of the expression $np\pi r^2_{sen} / \log(np)$ where n is the number of sensors and p is the probability of active sensors, is 1 form a sufficient condition for k-coverage. Although minimum k-coverage is valuable for surveillance kind of applications and other kinds of coverage such as an average k-coverage or the most k-coverage, may be more meaningful for other WSN applications. Moreover, it seems unsuitable to measure k-coverage for performance contrast due to its individual interest in the minimum coverage area of the network. For this reason we investigate the relative frequency of the exactly k-covered points in node deployment strategies.

3. DEPLOYMENT MODEL

In this paper, we examine three competitors of node deployment for a WSN: a uniform random, a square grid, and a Tri-Hexagon Tiling (THT) or Hexagonal Tiling (TH). Since the precedence of performance metrics varies in application specific WSNs, it is valuable to investigate a set of them.

For the duration of design phase of WSNs, the designer knows the number of sensor nodes n which are deployed in a given field in either random or deterministic manner. A circular field with radius R is measured in our experiments. We introduce three node deployment strategies together with their characteristics.

A Uniform Random: In [7] the uniform random deployment, each of the n sensors has equal possibility of being placed at any point inside a given field, as shown in fig, 8, 9 and 10. Therefore, the nodes are dotted on locations which are not known with certainty. In general, a uniform random deployment is assumed to be easy as well as cost-effective. Also, it is claimed that a uniform random deployment outperforms both the grid and the Poisson distribution deployments for k-coverage.

Square Grid: In WSN, we consider a grid based deployment is a good deployment and especially for the coverage performance shown in fig. 8(b). A grid deployment of n sensors in a circular field, where each of the n grid points hosts a sensor. The approximate length of a unit square, d', can be calculated as follows: The approximate area of a unit square with length d' can be computed by dividing the entire 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 $(\sqrt{n}-1)^2$ for the square grid in equation 1.From this relation, we derive Equation 1 for r_{sen}, the sensing radius. However, since we consider an initial adjustment for a starting point, Equation 1 cannot be applied directly. According to simulation results, Equation 2 gives more precise values than Equation 1. Although we use these equations to find out the r_{sen} (i.e., the length of a square, d') given n and R, this formula allows the estimated calculation of any one parameter out of n, r_{sen}, and R given the other two parameters.

$$r_{sen} = \sqrt{\frac{\pi R^2}{(\sqrt{n}-1)^2}} \quad (1)$$

$$r_{sen} = \sqrt{\frac{\pi R^2}{n}} \quad (2)$$

Tri-Hexagon Tiling (THT): The third approach is based on tiling. A tiling is the covering of the entire plane with figures which do not partly cover nor disappear any gaps. The tilings are also sometimes called tessellations. Among different tiling we use a semi-regular tiling (which has exactly eight different tiling) where each vertex uses the same set of usual polygons. A usual polygon has the same side lengths and interior angles. A semi-regular tiling that uses triangle and hexagon in the two dimensional plane 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 shown in fig. 8(c). In a way related to the square grid, an approximate formulation for r_{sen} can be found for THT. This approximate solution can be computed using Equation 3 [7].

$$r_{sen} = \sqrt{\frac{4\pi R^2}{3\sqrt{3}n}} \quad (3)$$

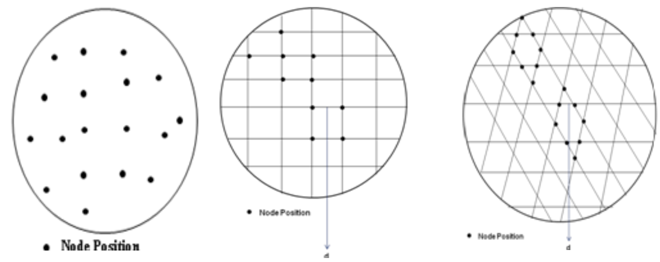

Fig. 8(a). Random Fig. 8(b). Grid Fig. 8(c). Tri-Hexagonal

Fig.8. The Node deployment for Circle field.

During the design phase of WSNs, we know the number of sensor nodes n which are deployed in a given field in either random or deterministic fashion. We consider another two field one is rectangle and other one is square field with sides is considered in our experiments shown in figure and formula given in table 1.

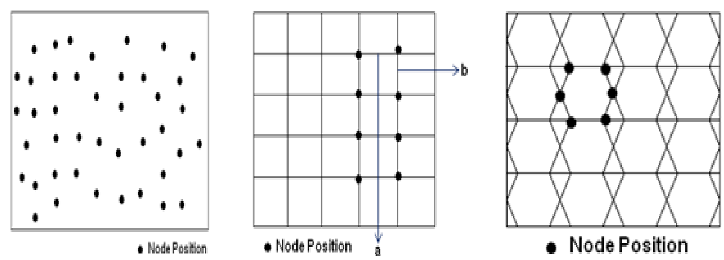

Fig. 9(a). Random Fig. 9(b). Grid Fig. 9(c). Hexagonal

Fig. 9. The Node deployment for Rectangle field.

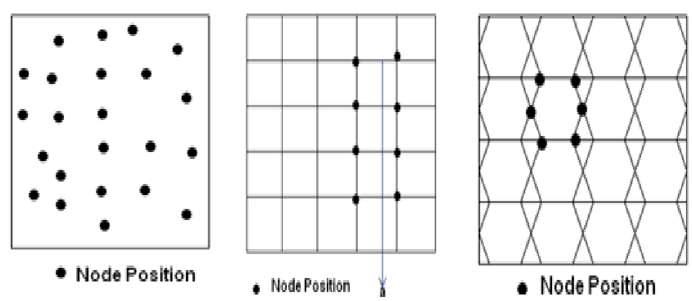

Fig. 10(a). Random Fig. 10(b). Grid Fig. 10(c). Hexagonal

Fig. 10. The Node deployment for Square field.

Table 1. Font sizes of headings. Table captions should always be positioned *above* the tables.

Field	Sides	Square Grid	Hexagonal
Circular	R	$r_{sen} = \sqrt{\frac{\pi R^2}{(\sqrt{n}-1)^2}}$ $r_{sen} = \sqrt{\frac{\pi R^2}{n}}$	$r_{sen} = \sqrt{\frac{4\pi R^2}{3\sqrt{3}n}}$
Rectangular	a , b	$r_{sen} = \sqrt{\frac{a \times b}{n}}$	$r_{sen} = \sqrt{\frac{2(a \times b)}{n}}$
Square	A	$r_{sen} = \sqrt{\frac{b \times b}{n}}$	$r_{sen} = \sqrt{\frac{2(b \times b)}{n}}$

4. RESULTS

In this section, we perform a performance evaluation for our three node deployment strategies. The primary factors for all experiments are: the number of sinks, the number of nodes, and the sensing region. For each deployment, the nodes are distributed over a circular, rectangle, and square field shapes and sinks are positioned at the Center of Gravity. Using the Java coding to display three shapes with node deployment strategies shown in fig. 11.

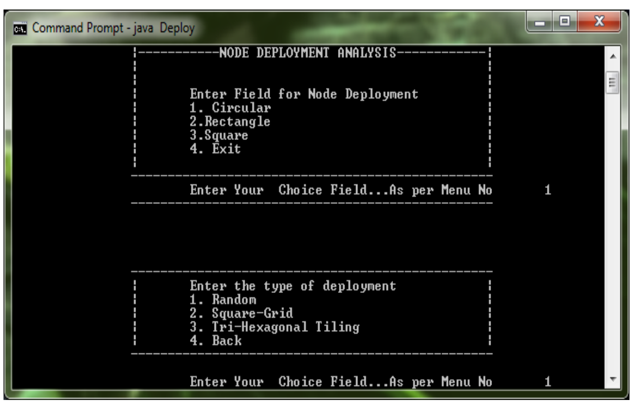

Fig. 11. The Menu design for three fields (Circular, Rectangular and Square).

Further, we build assumptions to compare our three strategies. Since we do not consider boundary condition in random deployment, square grid and Tri-hexagonal tiling. Therefore, in the case of the random deployment for circular, rectangle and square fields, we do a systematic sampling over the areas which are differing shown in fig. 12, 13 and 14.

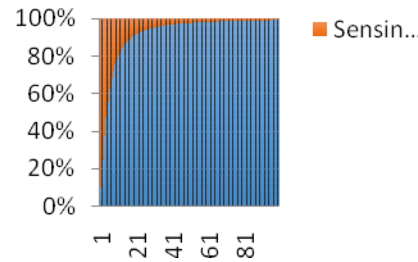

Fig. 12(a). Random Deployment in Circular

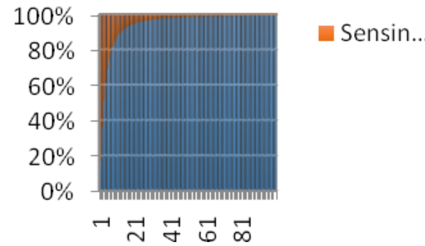

Fig. 12(b). Random Deployment in Rectangle.

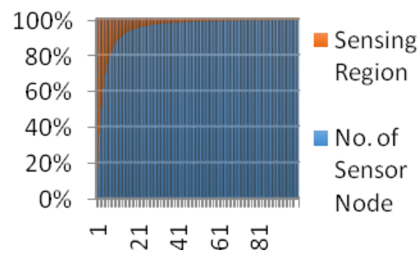

Fig. 12(c). Random Deployment in Square

Fig. 12. The Random Deployment in three different fields (Circular, Rectangular and Square).

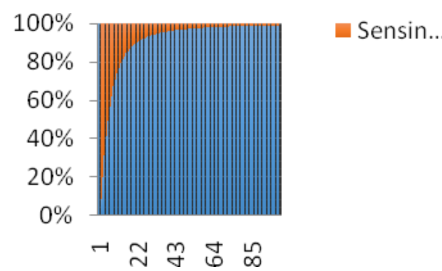

Fig. 13(a). Square Grid Deployment in Circular.

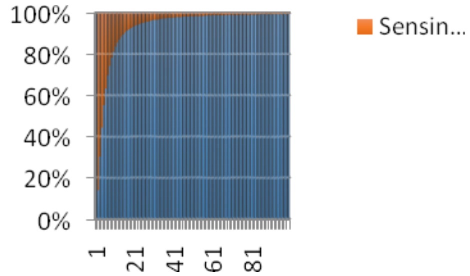

Fig. 13(b). Square Grid Deployment in Rectangle.

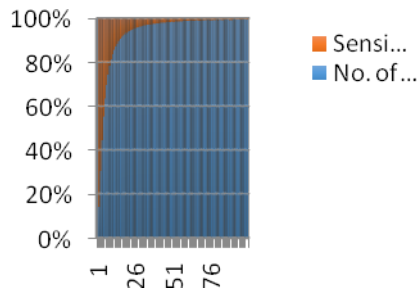

Fig. 13(c). Square Grid Deployment in Square

Fig. 13. The Square Grid Deployment in three different fields (Circular, Rectangular and Square).

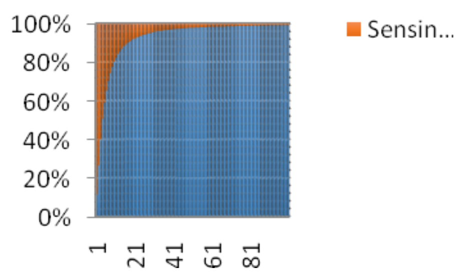

Fig. 14(a). Tri-hexagonal deployment in Circular.

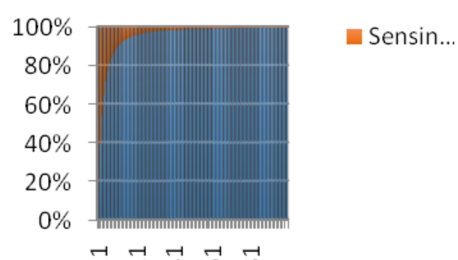

Fig. 14(b). Tri-hexagonal deployment in Rectangular.

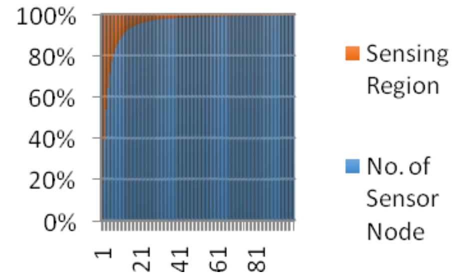

Fig. 14(c). Tri-hexagonal deployment in Square.

Fig. 14. The Square Grid Deployment in three different fields (Circular, Rectangular and Square).

5. CONCLUSION

We study the complete process of wireless sensor network about the deployment are summarized and analyzed. In the result section, we proposed three fields with three strategies. It seems that a random deployment in three fields is more or less comparable to a square grid for a large-scale network.

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