Comparative Analysis of Coverage in Wireless Sensor Network Using Distributed Dynamic Node Deployment Schemes

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Abstract

Node deployment plays an important role in the wireless sensor network. The proper deployment solves the basic problem in the wireless sensor network. The efficiency and lifetime increase with the choice of the node deployment. The importance of a good deployment strategy is also needed to be considered. In this paper three contenders of Distributed Dynamic node deployment for a sensor network are examined: a regular hexagon based, an octagon-square based and a tri-beehive based pattern. Performance and comparison are evaluated for all the three sensor node deployment strategies.

Keywords: Sensor Nodes, Deployment, Coverage Analysis, K-coverage

1 INTRODUCTION

Recent years have witnessed a growing interest in deploying a large number of sensors that collaborate in a distributed manner on data gathering and processing [1]. Sensor nodes are expected to be inexpensive and can be deployed in a large scale in harsh environment, which implies that sensor nodes are capable of operating unattended. Each sensor node is capable of only a limited amount of processing. But when coordinated with the information from a large number of other nodes, they have the quality to measure a given environment in complete detail. Thus, a sensor network can be described as a collection of sensor nodes which co-ordinate to perform some specific action.

These nodes can be deployed over a network in random or deterministic fashion. While the random node deployment is preferable in many applications, if possible, other deployments should be investigated since an inappropriate node deployment can increase the complexity of other problems in Wireless Sensor Networks (WSNs). Three competitors of node deployment for a sensor network: a uniform random, a square grid, and a Tri-Beehive based pattern. Since the priority of performance metrics varies in application-specific Wireless Sensor Networks (WSNs), it is worthwhile to investigate a set of them.

Thus, we have taken two major performance evaluation measures for all the three node deployment strategies, namely first one is the coverage analysis based on the K-coverage mapping and the other one is the distance dependent energy consumption in case of all three deployment patterns.

2 DEPLOYMENT STRATEGIES FOR WIRELESS SENSOR NETWORK

The Wireless Sensor Networks (WSN)'s applications can be generally classified into target tracking and area monitoring. In the target tracking scenarios, we concern if we can trace the moving object accurately. It seems that a denser infrastructure cause a more effective WSNs. However, if not deployed well, a denser network will lead to a larger number of packet collisions and traffic congestions. The number of sensors and the position of sensors affect the performance of tracking. In the area monitoring scenarios, we need to have enough sensors to avoid blind angle. The cost of larger sensors is another reason to devise good deploying strategy.

2.1 Classification of Deployment Strategies

In this section, we will first classify the deployment strategies [2]. The way with which the Wireless Sensor Network (WSN) is deployed provide a huge impact on its working and performance. A simple taxonomy is shown in figure (1). One branch of the figure (1) is deployment with all static sensor nodes and another is deployment with at least one mobile node.

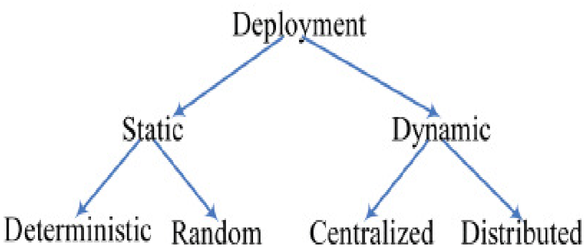

Figure 1. The taxonomy of the deployment

2.1.1 Static Deployment

In static device deployment, it can be further classified into two groups based on whether or not the placement points for all sensor nodes are planned accurately in advance. In static deployment strategy for Wireless Sensor Networks (WSN), all the sensor nodes are static in nature. All sensor nodes are applied in the field on fixed positions and they have restriction on their mobility. Following two sub-divisions of static deployment strategy are :

2.1.2 Deterministic Static Deployment

The deterministic static deployment is the most elaborate because the sensor topology is usually designed beforehand for best performance. However, in the situation with a lot of sensor nodes and the field unfriendly and uncontrollable, the deterministic static deployment may not work or can be difficult to deploy each sensor node as expected exactly. The sensor nodes are placed on the previously decided positions in the field. Some of deterministic protocols are grid-based deployment whose nodes are placed on the crossing points of the grids.

2.1.3 Random Static Deployment

Random deployment methods decide the density of a network rather than calculate each node's position like those in deterministic strategies. Using uniform distribution, we decide the interested area and the number of sensor nodes first. The random strategy is another choice. The sensor nodes are placed according to the condition of the area and thus the placement strategy of the nodes is not planned in advance. In random strategy, sensor nodes can be deployed according to uniform, Poisson, Gaussian, or other distribution model. Then deploy them as uniformly as possible by air-drop or other methods.

2.1.4 Dynamic Deployment

Dynamic deployment for Wireless Sensor Network (WSN) comes with a major difference in comparison to static one. That major difference is it include the liberty for the sensor nodes to move from their positions within the coverage area. As for the dynamic device deployment, it can be categorized into centralized and distributed methods.

2.1.5 Centralized Dynamic Deployment

In the centralized method, some of sensor nodes such as cluster heads or base stations decide their position themselves. After that, other nodes are deployed by those cluster heads or base stations. Thus we can state that the locations of sensor nodes are decided by a few nodes such as base stations or cluster heads.

2.1.6 Distributed Dynamic Deployment

The distributed dynamic deployment strategy allows each sensor node in the Wireless Sensor Network (WSN) to choose its location of operation itself. Thus in contrast to the centralized strategy, the location of the sensor nodes is not controlled and decided by the cluster heads or base stations. Nodes are deployed one at a time, with each node making use of data gathered from previously deployed nodes. The advantage of this approach is simplicity and clarity. Due to this sequential step, it usually takes more time to deploy than other concurrent methods.

Out of these various categories of the deployment strategies we have chosen three basic deployment patterns for evaluation namely Regular Hexagon pattern, Octagon-Square pattern and the Tri-Beehive pattern [4]. All of the above mentioned node deployment patterns belong to the Deterministic Deployment classification.

2.1.6.1 REGULAR HEXAGON PATTERN

A circular field with radius R is considered where the sensor nodes are positioned on the intersection vertices of the regular hexagon mesh. Each hexagonal cell inside the circular field is symmetric with each other. In the regular hexagon deployment, each of the n sensors has equal probability of being placed at the vertices points inside a given field as shown in figure (2).

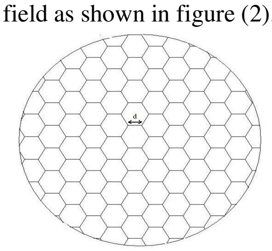

Figure 2: A Regular Hexagon Deployment Pattern

2.1.6.2 OCTAGON-SQUARE PATTERN

A grid-based deployment is considered as a good deployment in WSN, especially for the coverage performance. It will be more interesting if we apply our study over a hybrid pattern i.e. a pattern made up with two different geometrical shapes. There are several grid based designs like as unit square, equilateral triangle, regular hexagon etc. The Octagon-Square Grid deployment pattern is used for the evaluation purpose because of its natural placement strategy over a unit octagon-square pair.

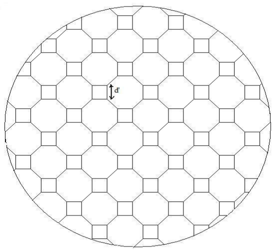

Figure 3: A Octagon-Square node deployment pattern

Octagon-Square based node deployment pattern is depicted above in figure (3). Each of the sensors are deployed on the intersection points of the grid in a considered circular field with radius, say R. The Octagon-Square grid pattern within a circular field with radius R is assumed to be symmetric tessellations i.e. all the unit cells within the circular field have equal edge length d and thus equal area within each unit square cell and each unit octagon respectively.

2.1.6.3 TRI-BEEHIVE PATTERN

Tri-Beehive deployment pattern for Wireless Sensor Network (WSN) is based on tiling. A tiling can be considered as the covering of the entire plane with figures which neither overlap each other nor leave any gaps. Tilings are also sometimes called as tessellations. It is also an example of hybrid pattern or tessellation with a mix of two or more shapes. In Tri-Beehive tessellations, we have every vertex employed with the same set of regular polygons. A regular polygon has the same side lengths and interior angles. We consider a semi-regular tiling that uses triangle and hexagon in the two dimensional plane, the so-called 3-6-3-6 Tri-Hexagon Tiling.

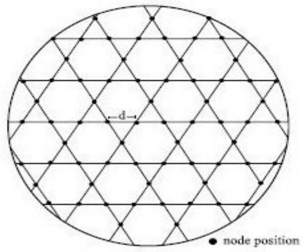

Figure 4: Tri-Beehive node deployment pattern

3 COVERAGE

The term coverage in the sense for the network can be considered as the maximum range or area up to which the network is able to send or receive the data and also able to track the objects for monitoring them. In Wireless Sensor Network (WSN)s, the simple reason for checking coverage is to provide the high quality of information in the region of interest[5]. 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.

3.1 K-Coverage

A network is said to have k-coverage if every point in it is covered by at least k sensors. If a particular point in the area which is being monitored by the Wireless Sensor Network (WSN) nodes is monitored by three sensor nodes, then that particular point of area is said to have 3-coverage.

3..1.1 Regular Hexagon Grid Node Deployment Coverage

In the regular hexagon grid, no matter what amount of 'n' is analyzed, a single cell is sufficient for the whole network coverage since it has symmetric cells. The relative frequency bar graph of the exactly k-covered points of a Regular Hexagon grid cell is shown in figure (5) between the percentage of the coverage achieved and the number value of K in K-coverage. The sensing radius, R_{sense} used for Regular Hexagon grid cell is 13 m.

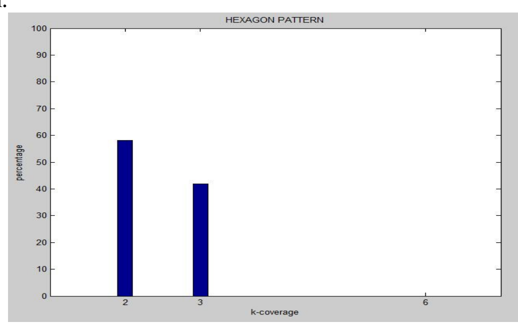

Figure 5: A graph for coverage analysis of Regular Hexagon grid pattern

As we can see in figure (5), more than half of the network is covered by two sensor nodes or 2-coverage. The remaining area is covered by exact 3-coverage. The share coverage of 6-coverage is nearly equal to null. The percentage values for the 2-, 3- and 6-coverage in the figure (5) are 58.045%, 41.96% and 0% respectively.Now, for computing the average coverage and the standard deviation we have to construct a table (1) showing the various values and the calculation.

Table 1: Average coverage and standard deviation for Regular Hexagon Pattern

K-coverage (x_i)	exactly k-covered points (w_i %)	weighted average (k-coverage*exactly k-covered points/100)	sample variance	standard deviation
1	58.0446	1.16089	0.2435	0.49
2	41.9554	1.2587		
3	0	0		
		Total 2.41959		

Thus, the regular hexagon grid has an average 2.42-coverage with a standard deviation of 0.49.

3.1.2 Octagon-Square Grid Node Deployment Coverage

Octagon-Square Sensor node deployment pattern is analyzed based on the total number of cells due to the combination of a central octagon and four squares with same edge length. The relative frequency bar graph of the exactly k-covered points of a Octagon-Square grid cell is shown in figure (6) between the percentage of the coverage achieved and the number value of K in K-coverage. The sensing radius , R_{sense} used for Octagon-Square grid cell is 8m.
For computing the average coverage and the standard deviation, table (2) shows the various values and the calculation.

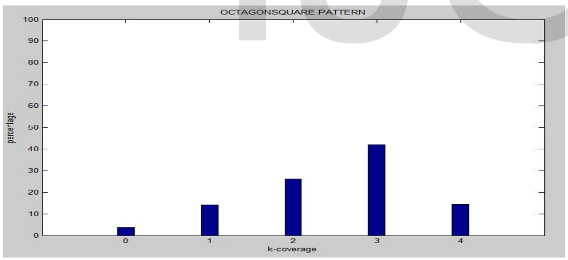

Figure 6: A graph for coverage analysis of Octagon-Square grid pattern

Table 2: Average coverage and standard deviation for Octagon-Square Pattern

K-coverage (x_i)	exactly k-covered points (w_i %)	weighted average (k-coverage*exactly k-covered points/100)	sample variance	standard deviation
0	3.5833	0	1.03287	1.0163
1	14.0979	0.14098		
2	26.1388	0.52278		
3	41.8770	1.2563		
4	14.3030	0.57212		
		Total 2.49218		

Thus, a Octagon-Square node deployment pattern has an average 2.49-coverage with standard deviation of 1.02.

3.1.3 Tri-Beehive Grid Node Deployment Coverage

Tri-Beehive Sensor node deployment pattern is analyzed based on the total number of cells due to the combination of triangle and hexagon. The relative frequency bar graph of the exactly k-covered points of a Tri-Beehive grid cell is shown in figure (7) between the percentage of the coverage achieved and the number value of K in K-coverage. The sensing radius, R_{sense} used for Tri-Beehive grid cell is 10 m.
The average coverage and the standard deviation for the tri-beehive node deployment pattern is shown in table (3) ahead.

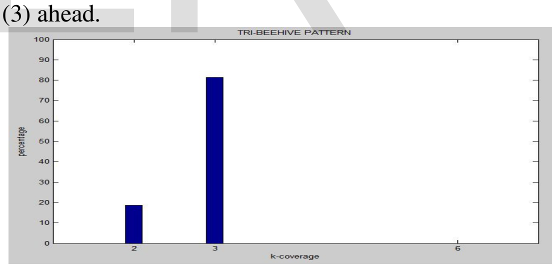

Figure 7: A graph for coverage analysis of Tri-Beehive grid pattern

Table 3: Average coverage and standard deviation for Tri-Beehive pattern

K-coverage (x_i)	exactly k-covered points (w_i %)	weighted average (k-coverage*exactly k-covered points/100)	sample variance	standard deviation
1	18.5335	0.37067	0.1510	0.38

2	81.466 5	2.4439	1	
3	0	0		
		Total 2.8147		

Thus, without counting the exact 6-coverage, a Tri-Beehive node deployment pattern has an average 2.81-coverage with standard deviation of 0.38.

4 CONCLUSION

A Wireless Sensor Network (WSN) can be composed of homogeneous or heterogeneous sensors, which possess the same or different communication and computation capabilities, respectively. The conclusion of this work points towards the Tri-Beehive deployment pattern as a better option for Wireless Sensor Networks (WSN) deployment. Although, its architecture planning may create some overhead. For coverage performance evaluation, a Tri-Beehive node deployment is better than the other strategies giving the average coverage of 2.82 with least standard deviation of 0.38. Thus, our first performance metrics gives Tri-Beehive Node Deployment Strategy as optimal choice for consideration. Next for the energy consumption analysis, it is shown that how the Tri-Beehive pattern is consuming the least energy of all under various sinks conditions.

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