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Node Placement and Coverage in Asymmetrical Area

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Abstract— ***What is the most important problem in sensor network designing is how to place sensors. Their arrangement can be designed carefully in order to build a surveillance system for optimization is very effective to achieve the desired design goals. With using the appropriate nodes placement, we can improve parameters of networks such as coverage, communication, energy consumption and longevity and optimize system performance according to our specified budget. Since the available resources and system settings depend on node placement and determine network performance range, wireless sensor networks have been regarded as crucial issues. In this survey, convex hull algorithm has been used to place nodes properly. The goal of our proposed method is to optimize the number of sensors, low power consumption and determine node placement to support a distributed sensor network in asymmetric area. As many areas in these common methods which do not require sensor placements have also been covered, the number of sensors in the desired area is being increased and subsequently it leads to energy consumption upsurge.***

Keywords— ***Convex Hull Algorithm, Coverage, Node Placement, Optimization, Wireless Sensor Networks***

I. INTRODUCTION

Recent advances in Micro-Electro-Mechanical Systems (MEMS) technology design small low-cost and low-power circuits and wireless communication equipments that makes to create a new technology called wireless sensor networks [1,2]. A sensor is an electronic device used for detecting and measuring a physical quantity into an electrical signal. In other words, sensors are devices that convert the aspects of physical reality into understandable aspects processed by the computer [3]. These networks with features such as low-power consumption, small size and low cost [4] can monitor a physical range as well, gather information from their environment and send it to sink for decision. Wireless sensor networks have some resource and design constraints. The greatest limitations of resources are energy consumption and coverage. Energy consumption is one of the most important factors to determine the lifetime of the network. Since sensor nodes have limited energy, recharge and placement of them is impossible.

In the past few decades, wireless sensor network applications have increased considerably. The main applications of this type of networks, habitat monitoring [5], military applications and tracking of military targets, health care monitoring, agriculture and animal husbandry and etc[6]. In wireless sensor networks, one of the noticeable goals is the maximum area coverage under surveillance. High degree of coverage is leading to greater precision in data collection. Due to variation in the number and types of sensors and their applications, interpretations and concepts have been proposed for coverage. Generally, coverage can define as one of the quality of service parameters in wireless network. The concept of coverage is service quality measurement of sensor performance and owing to the types of sensors and their applications, this notion is a very broad and wide. Coverage algorithms are divided into two categories: centralized and distributed. In centralized algorithms, the decision results are checked in the endpoints of node. In distributed algorithms, the decision process is decentralized and distributed between nodes. Decision process at each node uses only neighborhood information [7,8].

The coverage concept with regard to the many-robot systems was introduced by Gage [9] which includes area coverage, point coverage, and barrier coverage. By Choosing the method of sensor's exposure considering the applications, a type of sensors and environment in where sensors operate on are two forms: deterministic and random. Controlled node deployment is viable and often necessary when sensors are expensive or when their operation is significantly affected by their position; such scenarios include populating an area with highly precise seismic nodes, underwater WSN applications, and placing imaging and video sensors. On the other hand, in some applications random distribution of nodes is the only feasible option such as a battle field or a disaster region [10]. Thus given the constraints and the wide applications of wireless sensor networks designing the optimal node placement is a very challenging problem that has been proven to be NP-Hard for most of the formulations of sensor deployment [11][12][13].

In this paper, some important parameters such as number of sensors and coverage in the asymmetric environment for enhancing performance are optimized. In section 2, we summarize some of the related works about coverage in Symmetrical area. Section 3, the solution used to optimize the placement of nodes with convex hull algorithm will be described.

II. RELATED WORKS

Coverage has attracted a great deal of research attention due to its relation to optimization of resources in a sensing field. Maximizing the coverage and maintaining a lower cost of deployment have always been a challenge, especially when the monitoring region is unknown and possibly hazardous. An effective approach for energy conservation in WSNs is coverage deployment strategy. Many simulation results show that optimal deployment strategy can achieve a certain degree of coverage results with less number of nodes. The Art Gallery Problem, for example, deals with determining the number of observers and their placement necessary to cover an art gallery room such that every point is seen by at least one observer. The Art Gallery Problem was solved optimally in 2D and was shown to be NP-hard in the 3D case. In order to achieve deterministic coverage, a static network must be deployed according to a predefined shape [14]. Much of the published articles, consider a disk area that the sensor is located in the center and its radius is equal to the sensing field. Other works used a parameter being expressed with a ratio of covered area to total desired area to determine the amount of coverage [15]. Recent work has been performed in this field, used a more practical model for a range of sensors such as irregular polygon [16]. Dhillon and Chakrabarty have considered the placement of sensors on a grid approximation of the deployment region. They propose a greedy heuristic that strives to achieve the coverage goal through the least number of sensors [17]. Pompili, et al. [18] have investigated the problem of achieving maximal coverage with the lowest sensor count in the context of underwater WSNs. They proposed triangular grid. The idea, as depicted in Figure 1, is to pursue a circle packing such that any three adjacent and non-collinear sensors form an equilateral triangle. In this way, one can control coverage of the targeted region by adjusting the distance *d* between two adjacent sensors.

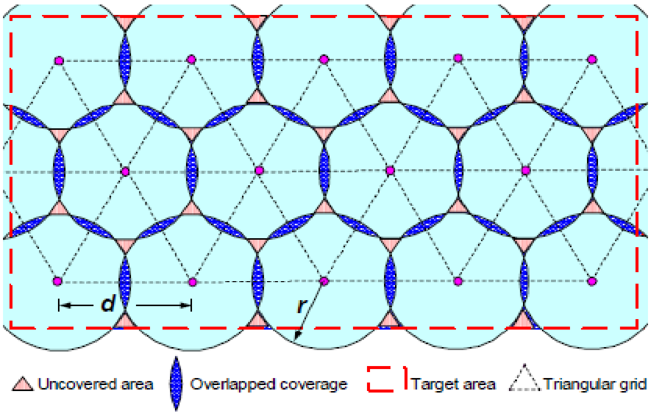


Fig. 1: Sensor placement based on a triangular grid. Coverage can be controlled by adjusting the inter-node distance "d". This figure is redrawn from [18].

The sensor placement problem is considered by Biagioni and G. Sasaki [19]. They opt to find a placement of nodes that achieves the coverage goals using the least number of sensors and also maintain a strongly connected network topology even if one node fails. The authors review a variety of regular deployment topologies, e.g., hexagonal, ring, star, etc. They argue that regular node placement simplifies the analysis due to their symmetry despite the fact that they often do not lead to optimal configurations.

III. PROBLEM STATEMENT

In this paper we presented a coverage method used in asymmetric area. Using this method for node placement reduces the number of sensors and saving energy rather than previous methods.

Convex hull problem [20] for two-dimensional set of points that can be defined as follows:

The convex hull of a set Q of points is the smallest convex polygon P for which each point in Q is either on the boundary of P or in its interior. We denote the convex hull of Q by CH(Q). This algorithm output the vertices of the convex hull in counterclockwise order.

As can be seen from figure 2, every vertex of CH(Q) is a point in Q. This algorithm exploits this property, deciding which vertices in Q to keep as vertices of the convex hull and which vertices in Q to throw out. Processing vertices in the order of the polar angles they form with a reference vertex.

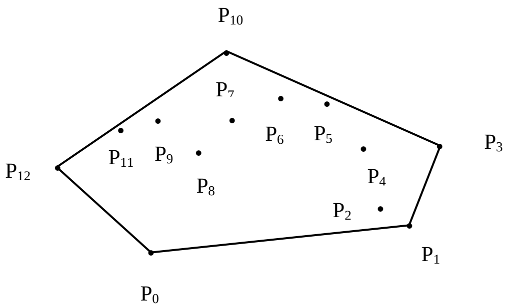


Fig. 2: A set points of $Q = \{p0, p1, ..., p12\}$ with its convex hull CH(Q) in gray.

We shall present this algorithm that compute the convex hull of a set of n points. The first, This algorithms runs in $O(n \log n)$ time.

```
let p0 be the point in Q with the minimum y- coordinate,
or the left most such point in case of a tie
let (p1,p2,…,pm) be the remaining points in Q,
        stored by polar angle in counterclockwise order around p0 (if more than
        one point has the same angle, remove all but the one that is farthest from
        p0)
PUSH (p0,S)
PUSH (p1,S)
PUSH (p2,S)
for i ← 3 to m
    do while the angle formed by points NEXT-TO- TOP(S),
    and pi makes a nonleft turn
        do Pop(S)
        PUSH (pi,S)
returns S
```

For node placement in wireless sensors on an area, we have several different methods. In our problem, there exist some sorts of areas which are network coverage targets, like military areas whereas the only available data is their coordinate. The area coverage by wireless sensor network should be following several major goals:

1- The minimum number of sensor nodes is used.
2- All regions are covered by sensors.
3- Sensors have the least overlapping.

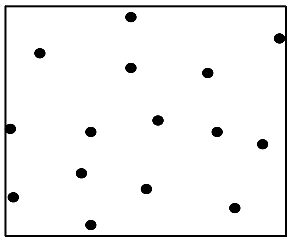


Fig. 3: Distribution of military area in a region

Assume a set of sensors, $S=S_1,S_2,\ldots,S_n$, in a 2D area. Each sensor $S_i,(i=1,\ldots,n)$ is located at coordinate (x_i,y_i) and has a sensing range of r_0 which is usually called sensing radius. Sensors will be placed by distance r in their own rows and in separate rows, they have distance $\frac{\sqrt{3}}{2} r_0$. According to these distance the area will be covered. The main strategy is to achieve the above objectives according to the inscribed regular hexagonal structure [21] within the sensing field of sensors.

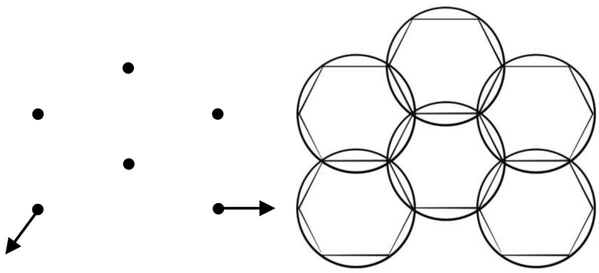
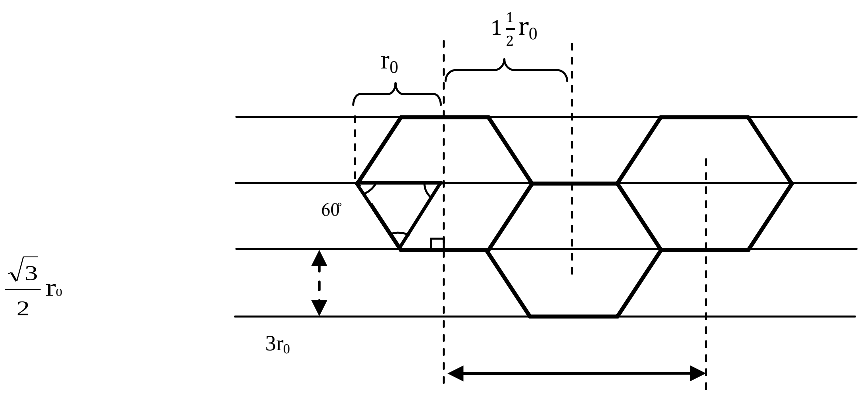


Fig. 4: The sensor sensing model based on hexagonal structure with sensing radius r_0

By assuming this hypothesis is right and selecting the method as the best coverage, we will reach a series of calculation:



The distance between center of two sensors on a line

Fig. 5: Demonstration distance between sensors

As mentioned earlier, we generate the convex hull associated with the sensitive military points and then according to the method that was introduced, we began to layout area by selecting one side of convex hull randomly and call it the baseline. Until being in the convex hall, the rest of the lines will be continued according to formula (1). By considering the baseline equation is $y=mx+n_1$, to find new line equation $y=mx+n_2$, we have:

$$(1) \qquad {}_2 = n_1 \pm d\sqrt{m^2+1}$$

Note: “d” is distance between lines

With regarding to relation (1), all of the parallel lines have been generated. Turning to the arrangement of sensors, It is necessary to create formula to place sensors on the parallel lines with desired distances. This formula obtains from line equation intersection and circle. Regarding the first point $A(x_A,y_A)$ and new point $B(x_B,y_B)$ on baseline $(y=mx+n)$, we have:

$$\Delta = (mn - x_A - my_A)^2 - (m^2+1)(x_A^2 + y_A^2 + n^2 - r_0^2 - 2y_A n) \qquad (2)$$

$$\begin{cases} x_B = \dfrac{-(mn - x_A - my_A) \pm \sqrt{\Delta}}{m^2+1} \\ y_B = mx_B + y_A - mx_A \end{cases} \qquad (3)$$

Now we start nodes’ arrangement on the baseline and according to presented structure, as long as the sensors are located inside the convex hull, arrangement will be continued.
After ensuring the placement of sensors on the all possible points on the baseline, it is necessary to find the first node coordinate to start arrangement correctly. Firstly, for this work, we find equivalent point of the first node from the first line on the second line and then moved on the size of 1.5 r_0 on this new line. For this purpose, if a point such as [a,b] considered on the line $y=mx+n_1$, then the equation of perpendicular line passing through that point is:

$$(4) \qquad \frac{1}{\imath} x + (m + \frac{1}{m})a + n_1$$

According to relation 4 and line equation $y=mx+n_2$, equivalent point coordinate on the new line can be obtained by relation 5:

$$(5) \qquad : a + \frac{m(n_1 - n_2)}{m^2+1}$$

Now, by determining starting point on the new line, all the things being done for the first line, will be repeated this for every line. By continuing this procedure, the entire area of polygon will be carpeted, as we shown in figure 6.

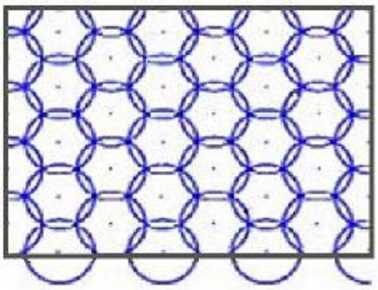


Fig. 6: The placement of nodes according to the distance mentioned

Algorithm:
1-The first equation side of Convex hull $y=mx+n_0$ (baseline) is specified. The starting point of this segment is the first sensors node coordinate. We add this to list.
2-We continue the nodes’ arrangement on the baseline as long as being in the convex hull and then add these coordinate to the list.
3-Obtain the next equation of parallel line until within the convex hull (in $y=mx+n_i$ equation, n_i is computed), then shifted baseline to the next line and we get the starting point of arrangement. Then go to step 2.

The above algorithm is important to note that how to recognize a node located within the convex hull or not? By knowing that if point is within the convex hull, provides counter clockwise with all points of the sides of the polygon and leads to an algorithm that runs in $O(nh)$ time, where h is the number of vertices.

IV- Conclusion

In this paper, convex hull algorithm has been used to place nodes properly. The goal of our proposed method is to optimize the number of sensors, coverage and determine node placement in an asymmetric area. As many areas in these common methods which do not require sensor placements have also been covered. This factor increases the number of sensors in the desired area and subsequently it leads to energy consumption upsurge. By using this method, we can significantly reduce the number of sensors and covered the desired area. Also, this algorithm runs in $O(n \log n)$ time and operates faster than other algorithms.

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