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Research on node coverage in agricultural wireless sensor networks based on deterministic coverage

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Abstract. The application of wireless sensor network in agriculture has always been a concern. In the research of wireless sensor network extension, coverage problem is one of the hot issues in wireless sensor network. Research on the node coverage of agricultural wireless sensor networks based on deterministic deployment is of great significance to improve the coverage quality of agricultural wireless sensor networks and reduce energy consumption. According to the feature of deterministic coverage of wireless sensor network nodes in the agricultural field, this paper summarizes and analyzes the existing deterministic coverage schemes, and proposes to determine the minimum number of nodes according to the size of the repeated coverage area, which provides ideas for the problem of node coverage with deterministic area characteristics in the agricultural field.

Keywords: wireless sensor networks, agriculture, deterministic coverage, minimum number of nodes, repeated coverage area.

1. Introduction

Wireless sensor network (WSN) is considered to be one of the technologies that will have a huge impact on the 21st century. It is an infrastructure-free network consisting of a set of sensor nodes that are self-organized to collaboratively sense, collect and process information about sensed objects in the geographical area covered by the network, process this data to obtain detailed and accurate information, and finally transmit this information to the required users. The user observes the operation of the network through the management and analysis software of the terminal, and can manage and monitor the individual nodes in the network [1]. These features of wireless sensor networks are well suited to the needs of the agricultural sector. Their application in agriculture can effectively reduce human consumption, obtain accurate crop environment and crop information in an efficient and real-time manner, reduce the workload of farm management and improve the level of agricultural management intelligence. Therefore, its application in the agricultural field has a great prospect.

Among the many studies on the extension of wireless sensor networks, the coverage problem has been one of the hot issues in wireless sensor network research, and node coverage in the agricultural field is mostly based on deterministic area deployment. It is important to study the node coverage problem of agricultural wireless sensor networks based on deterministic area deployment to improve the quality of wireless sensor network coverage in farmland and reduce energy consumption, etc. At present, there are many insights on this research at home and abroad. The authors of literature [2] proposed a sensor node deployment method based on genetic algorithm to achieve deterministic area coverage based on the characteristics of genetic algorithm with parallel search and population seeking, but it can ensure the local optimum and cannot guarantee the quality of the coverage set. The authors of literature [3] used the universe algorithm to effectively reduce energy consumption and improve the coverage of nodes. The authors of literature [4] proposed a hole detection and repair strategy based on Voronoi effective coverage area for the problem of coverage holes in the operational state of wireless sensor networks, which effectively reduces the total number of nodes and the perceived overlapping area of the network. The authors of literature [5] proposed two sensor coverage algorithms, the maximum average coverage (MAX_AVG_COV) and the maximum minimum coverage algorithm (MAX_MIN_COV), based on the node deployment strategy of the grid and the greedy algorithm, to solve the inaccurate detection and the priority coverage of grid points under coverage optimization. The authors of the literature [6] proposed a new firefly-based clustering method for wireless sensor networks as a way to optimize WSN network nodes and improve node coverage, but with more boundary blind areas. The literature [7] identifies candidate location points through the most multilayer overlapping domain of target points and determines the final node location using genetic algorithm, which simplifies the coding work of genetic algorithm, greatly reduces the network deployment cost and achieves deterministic and optimal deployment of target coverage.

Most of the existing research is based on the maximum coverage area to determine the minimum number of nodes. In order to meet the specific situation of achieving repeated coverage for a specific area in the agricultural field, this paper proposes to determine the minimum number of nodes based on the size of the repeated coverage area to provide ideas for the node coverage problem of deterministic area characteristics in the agricultural field.

2. Methods

2.1. Model assumptions

In order to further investigate the coverage problem of wireless sensor networks and to facilitate the simplification of the problem, the following assumptions are made in this paper.

(1) The sensing model of the sensor nodes uses a Boolean sensing model.

(2) Homogeneity of each sensor node.

(3) When the covered area is partially in a rectangular area, it still counts as a node.

(4) Each sensor node is evenly distributed within the monitoring area and the coverage area is approximately a garden.

Let G be the area to be covered (its area is $(X * Y)$), the area of the repeated coverage area as a percentage of the area of the node coverage circle is k and the radius of the circle to be covered is r and the chord length is L and the arc length is l and the angle of the center of the circle corresponding to each chord is θ. The distance from the chord to the center of the circle is d. If the nodes are located at coordinates (x, y), then the problem is formulated as follows: A particular repetition region is known, the ratio of its area to the area covered by the nodes is k, and there exists a way of covering it that minimizes the number of nodes used.

2.2. Description of the method

In studying the problem of determining the area coverage, the area is first divided, and each area is divided by placing a sensor node, the coverage of the nodes is interconnected, and thus the whole area is covered, then the area is divided in such a way that the problem of area division is equated to the polygon mosaic problem for the first time in this paper.

Lemma 1: In a regular polygon, there are only three shapes that can be laid out in a plane figure without voids: a regular triangle, a square and a regular hexagon (the regular polygon tessellation rule).

Since each sensor node is isomorphic, a homomorphic tessellation is used in the coverage process. This paper briefly demonstrates Lemma 1 through the following process: The tessellation problem requires two basic features to be satisfied: (1) the sum of the angles at the tessellation point is equal to 360 degrees; (2) the tessellation edges are equal. Let the side length of a regular polygon be and the interior angle be then we have

$$\theta = \frac{180^\circ \times (n-2)}{n} \tag{1}$$

Let the number of neighboring edges of each vertex of the polygon be $m(m \geq 3, m \in N^*)$, then we have

$$m = \frac{360^\circ}{\theta} \tag{2}$$

From the above equation, we can obtain: when the number of vertex-adjacent sides is 3, the number of polygonal sides is 6; when the number of vertex-adjacent sides is 4, the number of polygonal sides is 4; when the number of vertex-adjacent sides is 6, the number of polygonal sides is 3. Therefore, in the process of dividing the determined area without voids it is only possible to divide it for positive triangles, positive quadrilaterals and positive hexagons.

For different division methods, the ratio k of the repeated coverage area to the coverage area of the nodes has different values. Let the polygon side length of the divided area be n. Two nodes are selected to cover the physical model shown in Figure 1, and the relationship between their n and k is explored, and the relationship between n and k is found to be as follows:

$$\frac{\frac{2\pi}{n} - \sin\frac{2\pi}{n}}{\pi} = k\% \tag{3}$$

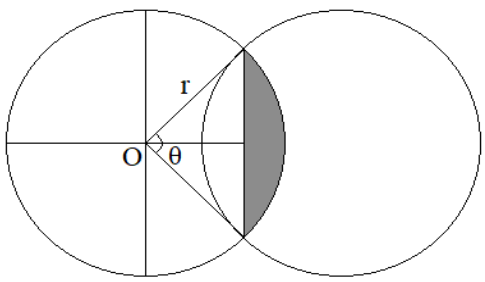

Figure 1. Physical model of node coverage.

From the above equation, we know that the value of k is certain when n is taken to different values. The values of k are calculated to be K_1= 39.1002, K_2= 18.169 and K_3= 5.7669 when n is taken as 3, 4 and 6 respectively. Therefore: when $k_2 \leq k \leq k_1$, the least number of nodes is used to divide the region by a square triangle; when $k_3 \leq k \leq k_2$, the least number of nodes is used to divide the region by a square quadrilateral; and when $0 \leq k \leq k_3$, the least number of nodes is used to divide the region by a square hexagon. When is used, the number of nodes is minimized. Thus, for a given area of repeated coverage at k_0, the value of n can be calculated using the following inequality:

$$\frac{\frac{2\pi}{n} - \sin\frac{2\pi}{n}}{\pi} \geq k\% \geq \frac{\frac{2\pi}{n+1} - \sin\frac{2\pi}{n+1}}{\pi} \tag{4}$$

3. Results

3.1. Study and comparison of three node coverage models

3.1.1. Positive triangle overlay. When a square triangle is chosen to delineate the area at $k_2 \leq k \leq k_1$, each sensor node is located on the vertex of the triangular grid (as shown in Figure 2), and three circles of the same radius intersect two by two, and when the length of the square triangle sides is $\sqrt{3}$ times the radius of the circle, both sensing and communication capabilities are ensured, while seamless connectivity and coverage are achieved [8].

Let the number of nodes be N_n(n is the number of polygon edges), and in the area to be covered G, the model of positive triangle coverage is shown in Figure 2, from which the number of nodes covered by positive triangles can be derived as follows

$$N_3 = \left\lceil \frac{X}{\frac{\sqrt{3}r}{2}} \right\rceil * \left\lceil \frac{Y}{\frac{3r}{2}} \right\rceil \tag{5}$$

($\lceil\bullet\rceil$ is an upward rounding function)

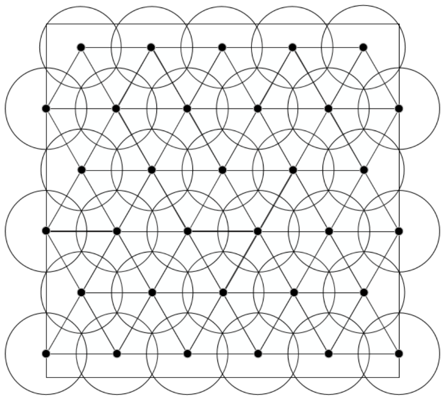

Figure 2. Positive triangle overlay model.

3.1.2. Positive quadrilateral cover. When $k_3 \le k \le k_2$ is chosen to divide the region, the quadrilateral is the inner quadrilateral of the node-covered circle, i.e. the length of the quadrilateral is $\sqrt{2}r$. At this time, the four circular domains intersect each other, and the intersection part is the smallest and the area of the circular domain is the largest [9]. At this point, let the number of nodes be N_n(n is the number of polygon sides), in the region G to be covered, the quadrilateral coverage model is shown in Figure 3, which can be derived from the number of nodes covered by the quadrilateral as follows:

$$N_4 = \left\lceil \frac{X}{\sqrt{2}r} \right\rceil * \left\lceil \frac{Y}{\sqrt{2}r} \right\rceil \tag{6}$$

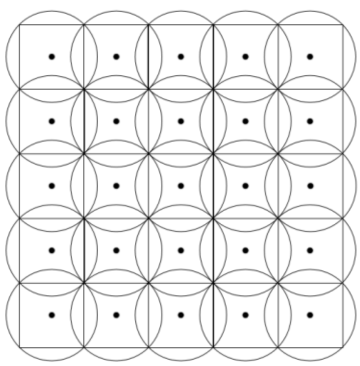

Figure 3. Positive quadrilateral overlay model.

3.1.3. Positive hexagonal overlay. When $0 \leq k \leq k_3$ is chosen to divide the region, the positions of the sensor nodes are arranged. In the area G to be covered, the coverage model is shown in Figure 4, and it is easy to obtain that the distance between adjacent sensors is $\sqrt{3}r$, every three circles intersect at a point two by two, the intersection part is the smallest, and the area G achieves seamless coverage. From this, the number of nodes covered by the positive quadrilateral can be derived as

$$N_6 = \left\lceil \frac{X}{\sqrt{3}r} \right\rceil * \left\lceil \frac{Y}{\frac{3r}{2}} \right\rceil \tag{7}$$

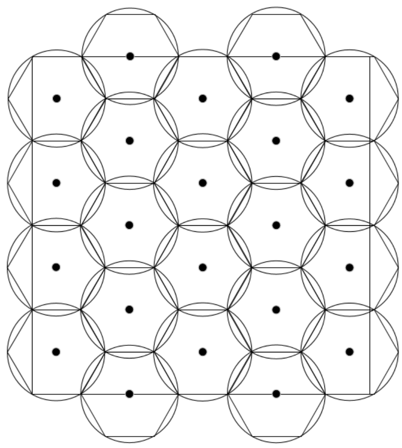

Figure 4. Positive hexagonal overlay model.

3.1.4. Three types of coverage connectivity. In wireless sensor networks, coverage and connectivity are two important indicators to evaluate the performance of sensor networks. The coverage problem has been studied above according to the area of repeated coverage area, and the connectivity problem of its three coverage methods is analyzed below. Let the sensing radius of the sensor node be r and the communication radius be R_c , the literature [9] proved that the communication radius of R_C for the square triangle, square quadrilateral and square hexagonal coverage methods are $2\sqrt{3}r$、$4r$、$\sqrt{13}r$ respectively. The literature [10] demonstrates that the communication radius is proven to be at least twice the sensor sensing radius, i.e. $R_c \geq 2r$, to ensure complete coverage of the entire surveillance area and connectivity of the network. The literature [11] demonstrates that if 90% of a sensor's sensing area needs to be covered by its neighbors, then five neighbors are necessary; if a wireless node has more than four neighbors, more than 90% of its transmission range can be covered by its neighbors. Therefore, to cover the entire detection area of a given node, that node needs at least three and at most five neighbor nodes for one-hop communication. This gives the coverage and connectivity requirements for all three division methods.

4. Discussion

The development of farmland wireless sensor networks helps to achieve technology for agriculture, and their determination of area repetition coverage determines precision agriculture development. This paper determines the polygon coverage method based on the determined area repetition coverage, calculates the minimum number of nodes, and finally analyses its connectivity. It is concluded that the polygonal coverage method based on the determined area repetition rate satisfies both coverage and connectivity requirements. Therefore, this paper can achieve complete coverage with a small number of nodes, which improves the node utilization rate and provides a new idea for the development of smart agriculture

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