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Deterministic Deployment for Wireless Image Sensor Nodes

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Abstract: Wireless sensor networks composed of camera enabled source nodes can provide visual information of an area of interest, potentially enriching monitoring applications. The node deployment is one of the key issues in the application of wireless sensor networks. In this paper, we take the effective coverage and connectivity as the evaluation indices to analyze the effect of the perceivable angle and the ratio of communication radius and sensing radius for the deterministic circular deployment. Experimental results demonstrate that the effective coverage area of the triangle deployment is the largest when using the same number of nodes. When the nodes are deployed in the same monitoring area in the premise of ensuring connectivity, rhombus deployment is optimal when $\sqrt{2} < r_c / r_s < \sqrt{3}$. The research results of this paper provide an important reference for the deployment of the image sensor networks with the given parameters.

Keywords: Circular deployment, deterministic deployment, directional sensors, perceivable angle, wireless image sensor nodes.

1. INTRODUCTION

With the rapid development of wireless communication technology, wireless sensor network has become a hot research topic. Wireless sensor networks (WSNs) consist of many cost-effective miniature sensor nodes are capable of computation, communication and sensing [1, 2], WSNs system mainly focuses on data acquisition, accurate processing and effective transmission [3], and has provided tremendous benefit for applications such as tracking, surveillance, disaster monitoring, home automation, industrial control, battlefield surveillance, and environmental monitoring [4, 5].

Node deployment is the first step in wireless sensor networks [6]. The purpose is to establish a powerful system with the nodes having limited perception and energy constraints [7]. Node deployment is directly related to accuracy, integrity and effectiveness of the network monitoring information.

Currently, most research work related to node deployment focuses on the omni-directional sensing model [8]. Omni-directional sensing networks are typically used to achieve simple data acquisition, transmission and processing. Most study on deployment of omni-directional sensing model concentrated on the random deployment of target coverage [9], regional coverage deployment [10-11] and deterministic deployment [12]. For area deterministic deployment, it usually adopts normalized covering algorithm. Reference [13] discussed various normalized covering algorithms. However, according to the importance in different monitoring regions, monitoring tasks have different requirements. For some special regions, comprehensive data (such as images and videos) are required. In [14], the impact of resource constraints was analyzed based on the performance of WISNs. Commonly used image / video sensors have a direction of environmental data. The perceived direction is only in one area. The existing research on image sensor deployment often uses random deployment. Reference [15] proposed an integer linear programming and distributed approximation algorithm to determine the direction of sensor nodes. In [16], a greedy algorithm was presented. Sung and Yang [17] utilized the structure and characteristic of Voronoi cells and proposed a new solution for target tracking in visual/camera sensor networks. In [18], an observation correlation coefficient was developed to describe the correlations between images by studying the sensing model and deployment of cameras in the network. A camera sensor activation scheme for target tracking in WVSN was also proposed. Random deployment is a more affordable method, but it cannot guarantee full coverage of the whole detection area. It is generally suitable for the environment with less coverage requirement. For a relatively fixed network status or application environment, node position information and node density are known, manual deployment of wireless sensor nodes, namely certainty deployment, can be used. For the deterministic deployment method, research usually focuses on target coverage. Reference [19] put forward a method for optimal deterministic deployment of a target coverage. The target coverage does not guarantee that the monitoring area is completely covered.

The static area coverage of deterministic specifications covering algorithm was adopted in this paper to study the deployment of wireless image sensor node. The effects of perceivable angle of the image sensor and deployment

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method on coverage overlapping area is also considered to analyze the deterministic deployment mode of image sensor node. Based on the study of this paper, we provide several methods to deploy the wireless image sensor with different parameters and some principle guidance for deterministic deployment of direction nodes.

The rest of the paper is organized as follows. In section 2, deployment method of WISNs is chosen. In section 3, the deployment of circular way is discussed. The simulation study is described in section 4. Finally, some conclusions remarks are made in section 5.

2. MODEL BUILDING

The perceptual model of nodes can be divided into fixed and rotatable. The rotatable model mainly considers the instantaneous sensing range. There exist some challenges such as delay monitoring, high energy consumption and complex algorithms. In order to meet the requirements of real-time monitoring and low energy consumption, in this study, we choose the static fixed sensing model due to its low computational complexity.

Fixed directional sensing model of sensor nodes are usually defined in the two-dimensional space. There are three directional sensing models: fan model, polygon model and irregular model. The fan model established by Ma et al [20-21] is a widely used model, where the perceived range is a fan-shaped region with a node as the center and the perceived distance as radius (see Fig. (**1**)). A parameter set (P, Rs, V, α) is used to represent the model, where P denotes the positions of nodes, Rs denotes the sensing radius, V indicates the sensing direction of the sensor node, and α is the offset of the visual angle of node.

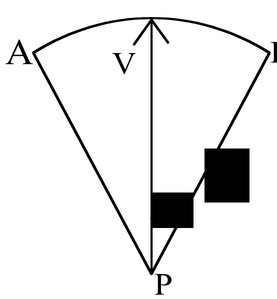


Fig. (1). The rotatable fan model.

This paper simplified the coverage model as a binary sensor model (BSM) which is also called 0-1 model or Boolean model [22]. The probability of the perceived target is based on the node sensing radius rS as the dividing line to generate induction and unknown induction states. Inductive quality of any spots of q can be expressed as:

$$p(s,q) = \begin{cases} 1 & d(s,q) \le r_s \\ 0 & d(s,q) > r_s \end{cases} \quad (1)$$

where d(s, q) is the straight line distance between s and q.

There are two deployment methods can achieve real-time completely coverage. One is the circular mode, which combines the sector sensing nodes into a circle. The other method is the tiled mode in which two relative nodes are in a group and two nodes in the same position are in a group as shown in Fig. (**2**).

In the circular deployment, the overlapping area is calculated as

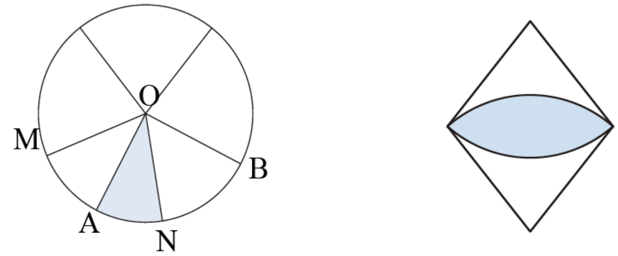
$$s_1 = \frac{1}{2} r_s^2 \left(\left\lceil \frac{p}{б} \right\rceil \times 2б - 2p \right). \quad (2)$$

The average overlapping area per node is

$$\bar{s}_1 = \frac{s_1}{\left\lceil \frac{p}{б} \right\rceil}. \quad (3)$$

In the tiled deployment mode, overlapping area of each node is

$$\overline{s_2} = \frac{1}{2} r_s^2 [2б - \sin(2б)]. \quad (4)$$



(a) The circular mode (b) The tiled mode

Fig. (2). The deployment methods.

The average overlapping area of these two deployment modes are compared in Fig. (**3**). When the perceivable angle is greater than 61.5º, the overlapping area of tiled deploy-

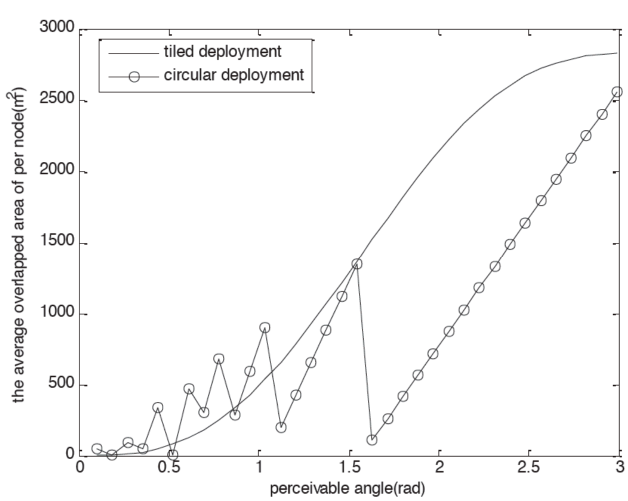


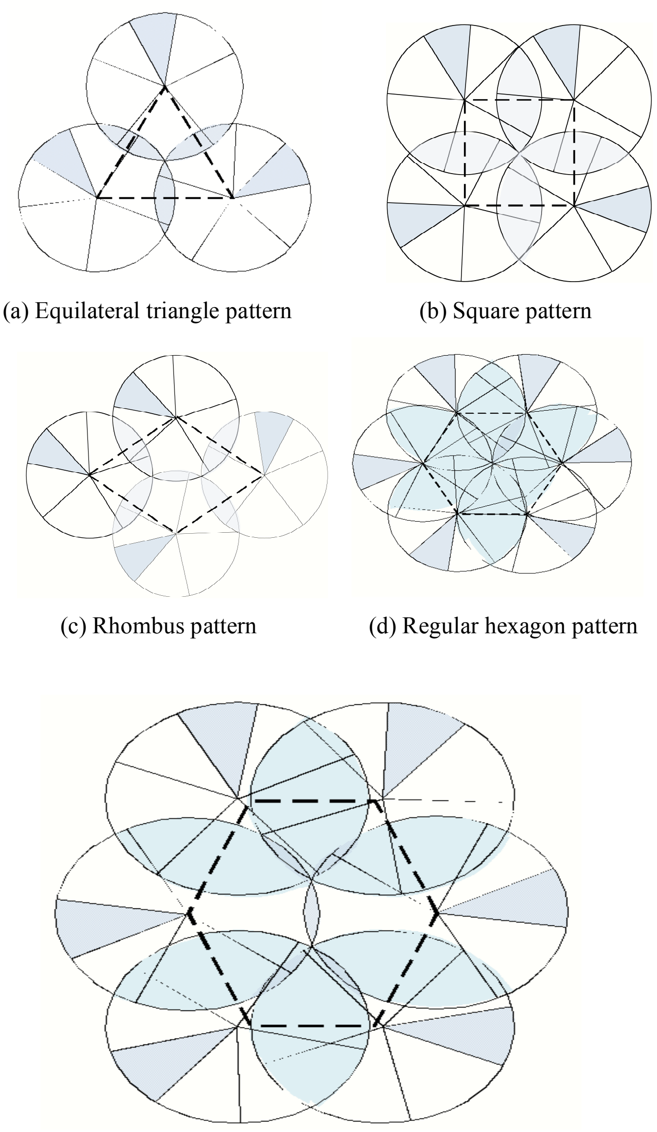
Fig. (3). The comparison between circular deployment and tiled deployment.

ment increases rapidly. In order to make the research more applicable to large value range of angle of image sensing nodes, circular deployment is used to study the region monitoring.

3. CIRCULAR DEPLOYMENT MODEL

3.1. Deployment Method

The normalized coverage algorithm is used to deploy the circle which consists of image sensor nodes. The deployment method is shown in Fig. (**4**).



(a) Equilateral triangle pattern (b) Square pattern

(c) Rhombus pattern (d) Regular hexagon pattern

(e) Irregular equilateral hexagon pattern

Fig. (4). Specifications of patterns.

3.2. Node Overlapping Area

In the circular deployment, only when the node angle could be divided exactly by 2π, there is no overlapping coverage; otherwise, it will produce coverage overlap because of the extra point of view, as a fan of AOB and MON in Fig. (**2**) overlap AON.

According to [23], when using different graphics deployments, the formula can be derived to calculate the overlapping area of a specification patterns:

$$S_1 = \frac{1}{2} r_s^2 [n(\theta - \sin\theta)] \tag{5}$$

where n indicates the number of overlapping in a graphical specification; θ is the central angle of overlapping area; and RS represents node sensing radius.

In the circular combination, the overlapping area caused by perception angle is the sectorial area:

$$S_2 = \frac{1}{2} r_s^2 (\left\lceil \frac{\pi}{\alpha} \right\rceil \times 2\alpha - 2\pi) \ . \tag{6}$$

All the overlapping coverage area:

$$S = S_1 + N_P \cdot S_2 \tag{7}$$

where NP indicates the number of round that is used to form a specification pattern, α is half of the node perceivable angle.

Each node of the average overlapping area is calculated as:

$$\overline{S} = \frac{\frac{S_1}{N_P} + S_2}{\left\lceil \frac{\pi}{\alpha} \right\rceil} \ . \tag{8}$$

In the specification pattern deployment, central angle of overlapping part of equilateral triangle, square, regular hexagon is set respectively as 60°, 90°, 60°. They can be directly calculated using Equation. (**5**).

For the rhombus as shown in Fig. (**5**), the overlapping area is composed of two parts:

$$S_1 = \frac{1}{2} r_s^2 [2(\beta - \sin\beta) + 8 \quad \theta\text{-}\sin\theta)] \tag{9}$$

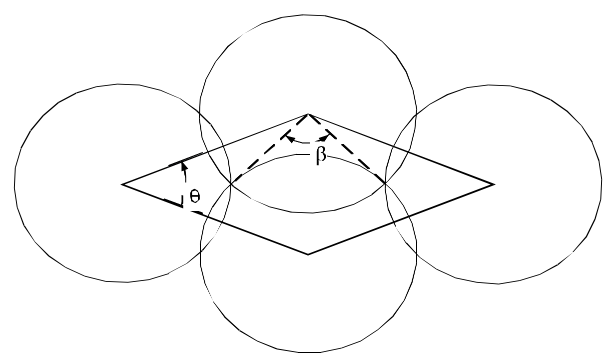


Fig. (5). Rhombus pattern.

For the irregular equilateral hexagon, as shown in Fig. (**6**), the central angles of overlapping areas are different, so need to be calculated separately.

In order to make the overlapping area small, it has to first determine the position of O1, O2, center of O1, O2 on point a, b respectively, O3, O4 and O1, O2 intersect at point c, the center of the O3 and O4 in the same line, in like manner, confirm the position of O5, O6, O5, O6 and O1, O2 intersect at point d.

The side length of irregular equilateral hexagon [24] is

$$L = \min\left\{2r_s\cos(\frac{\theta}{2}), r_c\right\} \quad (10)$$

and interior angle is

$$\theta = \pi - 2\arcsin(\frac{r_c}{2r_s}) \quad (11)$$

where rc represents the node communication radius.

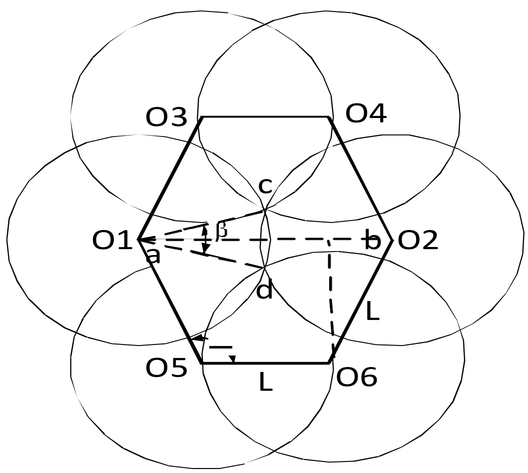


Fig. (6). Irregular equilateral hexagon pattern.

Draw two straight lines joining the center of O1 and c, the center of O1 and d, the length of is rs. The distance between O1 and O2 is:

$$x = \mathrm{L} + 2\times\mathrm{L}\times\sin(\theta - \frac{\pi}{2}). \quad (12)$$

The central angle of overlapping area caused by O1 and O2 is

$$\cos\frac{\beta}{2} = \frac{\frac{x}{2}}{r_s}. \quad (13)$$

The central angles of the overlapping area are calculated according to

$$\beta = 2\times\arccos(\frac{\frac{x}{2}}{r_s}) \quad (14)$$

$$\varepsilon = 2(\pi - \theta) - \beta. \quad (15)$$

The overlapping area of irregular equilateral hexagon is:

$$S_1 = \frac{1}{2}r_s^2[12(\varepsilon - \sin\varepsilon) + 2(\beta - \sin\beta)]. \quad (16)$$

4. SIMULATION ANALYSIS

In the experiments, the effective coverage and connectivity are used as the evaluation indices for the node deployment. The node sensing radius is 30 m, the range of communication radius is between 24 m and 60 m, and the sensing angle is within 6°- 172° (radian is 0.1rad to 3rad). All the simulations are carried out using MATLAB R2013a.

4.1. Deploy the Same Number of Nodes

In order to realize the full deployment of each type of specification, we select the same numbers of nodes to combine 3600 circles to study the effective coverage of the five deployment methods.

Since the interior angles of an equilateral triangle, square and regular hexagon are invariant, the central angles of overlapping area are certain value, the effective coverage area are computed as shown in Table **1**.

Angle in rhombus and irregular equilateral hexagon can be changed according to the ratio between communication radius and the sensing radius, under the premise of ensuring communication. With the same number of combination rounds, coverage area changes over interior angles as can be seen from Fig. (**7**).

Comparing Table **1** with Fig. (**7**), in the same number combination circles, the coverage area of equilateral triangle is the largest.

4.2. Deploy the Nodes in the Same Monitoring Area

A square area of S=1000 m×1000 m was selected as the experimental scene using connected coverage without considering the boundary effect in the monitoring region. The number of combined rounds were used and compared in different specifications graphics. The simulation results are shown in Fig. (**8**) and Table **2**. The equilateral triangle pattern, square pattern and regular hexagon pattern can be used to deploy within all scopes of the ratio; however, when use

Table 1. The coverage area of the same number combination round in different specifications of deployment.

The specification deployment	The coverage area when use 3600 combination round （m^2）
Equilateral triangle	9591758.473
Square	8329368.198
Regular hexagon	7807404

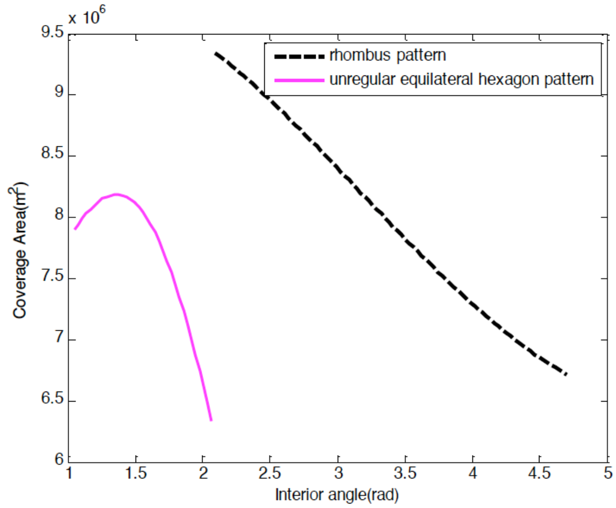


Fig. (7). The coverage area when using 3600 combination round deployed in rhombus and irregular equilateral hexagon pattern.

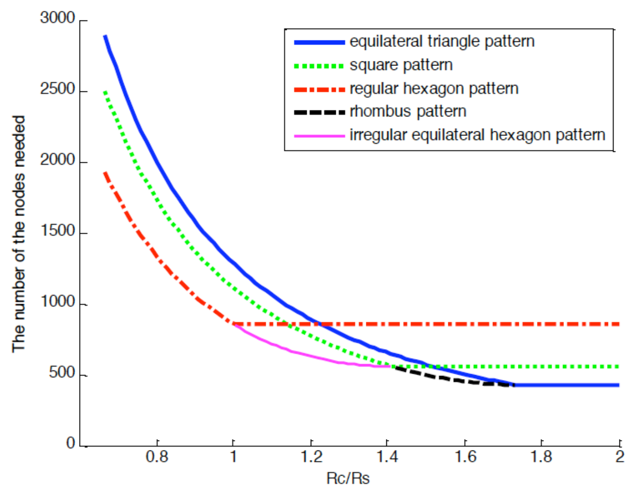


Fig. (8). The number of the combined rounds according to the radius proportion.

Table 2. Optimal regular deployment pattern according to the radius proportion.

r_c / r_s	**Optimal regular deployment**
$0 < r_c / r_s \leq 1$	Regular hexagon
$1 < r_c / r_s < \sqrt{2}$	Irregular equilateral hexagon
$r_c / r_s = \sqrt{2}$	Square
$\sqrt{2} < r_c / r_s < \sqrt{3}$	Rhombus
$\sqrt{3} \leq r_c / r_s$	Equilateral triangle

the rhombus pattern and irregular equilateral hexagon pattern, it should to ensure all the combined rounds are able to communicate with each other.

In a specification graphical deployment, the simulation results of using different overlapping averages of a node are illustrated in Fig. (**9**).

As can be seen from Fig (**9**), the five deployment patterns have the same change trend for average overlapping area, and the five lines are parallel to each other. In the five deployment patterns, the overlapped area of equilateral triangle pattern is the minimum. When the perceived angle is less than 20.3°, there is a small difference among equilateral triangle, rhombus, and regular hexagon. When the perceived

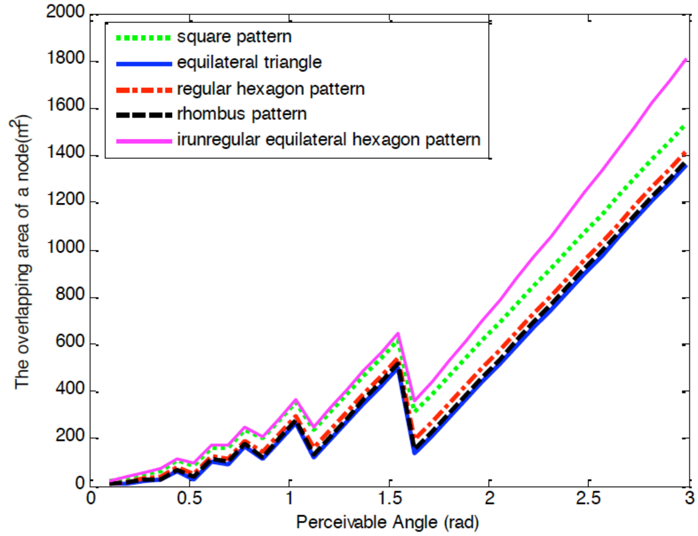


Fig. (9). The overlapping area of a node of different specification graphical deployment.

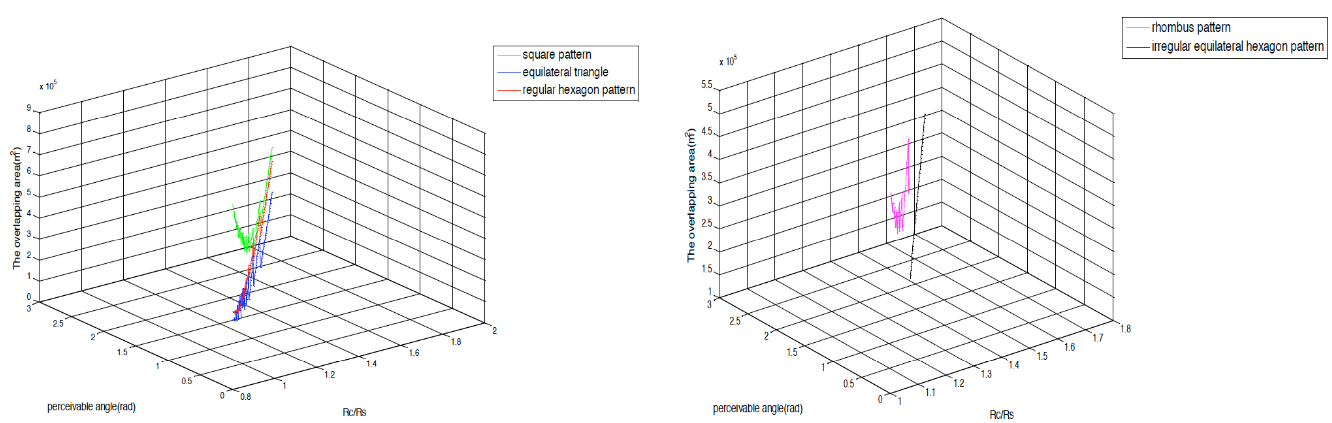
angle is more than 93.4°, five deployment node overlap area increases rapidly.

The effects of communication requirement of combined rounds and the perceivable angle of image sensors are comprehensively considered, calculate the total overlapping area of different specifications graphs in the same monitoring area.

From the simulation results in Fig. (**10**), the following conclusions can be obtained: (1) except the irregular equilateral hexagon pattern, although the rhombus pattern only suits for $\sqrt{2} < r_c / r_s < \sqrt{3}$, in the same monitoring area, the overlapping area of four deployment modes fluctuates with the perceived angle. (2) for the image sensor nodes with small perceivable angle, the square deployment may not be suitable. (3) when $r_c / r_s < 1.25$, the equilateral triangle deployment mode uses more combined rounds, but the overlapping area in the monitoring area is the least; when $\sqrt{2} < r_c / r_s < \sqrt{3}$, rhombus deployment is the optimal method.

5. CONCLUSION AND FURTHER WORK

In this paper, the deterministic deployment of wireless image sensor nodes were investigated. The coverage model was simplified to 0-1 model. By using the same numbers to deploy, analysis and contrast the effective coverage of different deployment mode. Synthetically considering the perceivable angle, the ratio of communication radius and sensing radius, the number of combined rounds are used in the same area. By analyzing the results, in the premise of ensuring the communication between nodes, image sensor networks deployed in normalization circular deployment method, with the same number of combined round, equilateral triangle deployment covers the largest area, in the same monitoring area, when $\sqrt{2} < r_c / r_s < \sqrt{3}$, rhombus deployment is optimal. Since the research model is an ideal model, it cannot describe the effect of node monitoring accurately. In our future work, we plan to use probabilistic models to carry out research analysis for deterministic circular deployment.



(a) Equilateral triangle, square, regular hexagon pattern

(b) Rhombus, irregular equilateral hexagon pattern

Fig. (10). The overlapping area of different deployments.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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