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DETERMINISTIC DEPLOYMENT for DIRECTIONAL SENSOR NODES

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Abstract- Node deployment is the key problem of wireless sensor network technology in application. The existing study on deployment of deterministic perceived nodes is simplified to the randomly deployment. In this paper, we take the effective coverage , connectivity and probability threshold as the evaluation indices to analyze the different deployment models. Experimental results demonstrate that the effective coverage area of the triangle deployment is the largest when using the same number of nodes; and if the probability is less than limits, tile deployment does not need to increase the node to ensure coverage. The research results of this paper provide an important reference for the deployment of the directional sensor networks with the given parameters.

Index terms*: *Deterministic deployment, directional sensor nodes,probability model

I. INTRODUCTION

With the rapid development of wireless communication technology, wireless sensor network has become a hot research topic, the demand of image, video and audio data is increasing, which leads to the emergence of directional sensor network. Node deployment is to establish a powerful system with the nodes having limited perception and energy constraints [1], is the first step in wireless sensor networks [2].

WSNs system mainly focuses on data acquisition, accuracy of processing and effective transmission[3], has provided tremendous benefit for applications such as tracking, surveillance, disaster monitoring, home automation, industrial control, battlefield surveillance, it also has great potential in environmental monitoring[4].

Accord to different methods of nodes deployment, wireless sensor networks can be divided into random deployment and deterministic deployment. Currently, most research work related to deterministic deployment focuses on the omni-directional sensing model [5]. For some special regions, comprehensive data (such as images and videos) are required. In [6], 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 directional sensor deployment often uses random deployment. Reference [7] proposed an integer linear programming and distributed approximation algorithm to determine the direction of sensor nodes. In [8], a greedy algorithm was presented. Sung and Yang [9] utilized the structure and characteristic of Voronoi cells and proposed a new solution for target tracking in visual/camera sensor networks.

Random deployment is a more affordable method, but it cannot guarantee full coverage of the whole detection area. For a relatively fixed network status or application environment, certainty deployment can be used. Most of the research on directional coverage are focused on the Boolean model [10] in random deployment. In [11], a coverage control strategy was presented. Reference [12] perceived direction of nodes and developed a node scheduling rule and distributed algorithm. Zhang et al.[13] presented a distribute 3D localization scheme for an irregular wireless sensor network using multidimensional scaling.

The Boolean model is an idealized model. In practical applications, sensor nodes are difficult to achieve full step type sensing, therefore, the probability model is more practical. The deployment of probabilistic sensing model mostly focuses on the random deployment. Peng et al. [14] proposed a direction adjustable linear model, which was basic on the direction adjustable sensing model. A probabilistic sensing model for directional sensor node was designed in [15] based on the existing directional sensing models which were always affected by uncertain sensing ability on their edges of two sides. In [16], a node deployment scheme was presented based on the perceived probability model for the wireless network nodes which were randomly deployed. In [17], an algorithm named MCAND is designed to achieve the given connected probability by adjusting the transmission power of each node dynamically, with the node degree equal to the minimum connected average node degree. Su et al. [18] proposed enhanced coverage algorithm to present the coverage probability of sensor nodes and the solution of expected values for coverage quality.

At present, little work has been done on probability model of deterministic deployment in area coverage of friendly accessible environment, so the study on the probability model of deterministic deployment has an urgent demand.

In this paper, the static area coverage of deterministic specifications covering algorithm was adopted to study the deployment of wireless sensor node, on the basis of satisfying the node communication, the deployment of probability perceived model of wireless image sensor node is investigated. In Section Ⅱ, deployment method of WISNs is chosen. In section Ⅲ, deployment algorithm based on the deterministic deployment is proposed. In Section Ⅳ, simulation experiments are carried out and analysis of the main influencing factors is provided. Finally, analysis of the results is given in Section Ⅴ.

II. COVERAGE MODEL

a. Sensing model

The 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 [19-20] 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. 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.

When using directional sensing node for monitoring area coverage, it can be divided into Boolean model (see Figure 1) deployment and probability model [21-22] (see Figure 2) deployment according to the node sensing model.

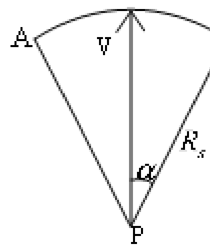


Figure 1. The rotatable fan model

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:

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

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

The perceptive range is a sector with a node as the center and the perceived distance as radius as shown in Figure 2.

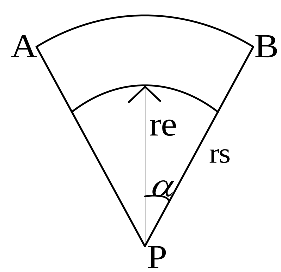


Figure 2. Non-rotating perceived probability model

The mathematical expression of the monitoring probability of arbitrary point q in the sensing area is defined as

$$p(s)=\begin{cases}0 & r_s\le d(s,q) \\ e^{-\lambda\alpha^{\beta}} & r_s-r_e\le d(s,q)\le r_s \\ 1 & r_s-r_e\ge d(s,q)\end{cases} \qquad (2)$$

where, $\alpha = d(s,q) - (r_s - r_e)$, λ、β is the attenution coefficient when $d(s,q)$ changes in loop region $(r_s - r_e) \sim r_s$.

b. Deployment method

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 Figure 3.

In the circular deployment, the overlapping area is calculated as

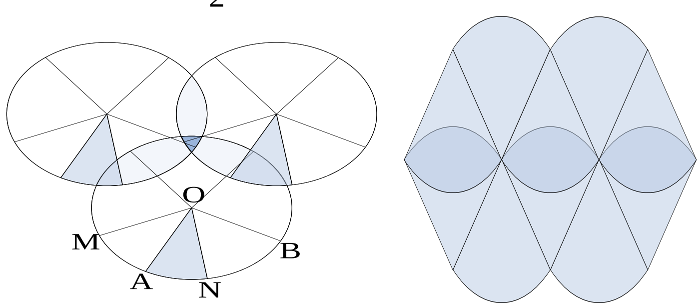
$$s_1 = \frac{1}{2} r_s^{\,2} (\left\lceil \frac{\pi}{\alpha} \right\rceil \times 2\alpha - 2\pi) \qquad (3)$$

The average overlapping area per node is

$$\bar{s}_1 = \frac{s_1}{\left\lceil \frac{\pi}{\alpha} \right\rceil} \qquad (4)$$

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

$$\overline{s_2} = \frac{1}{2} r_s^{\,2} [2\alpha - \sin(2\alpha)] \qquad (5)$$



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

Figure 3. The deployment methods

The average overlapping area of these two deployment modes are compared in Figure 4. When the perceivable angle is greater than 61.5°, the overlapping area of tiled deployment 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.

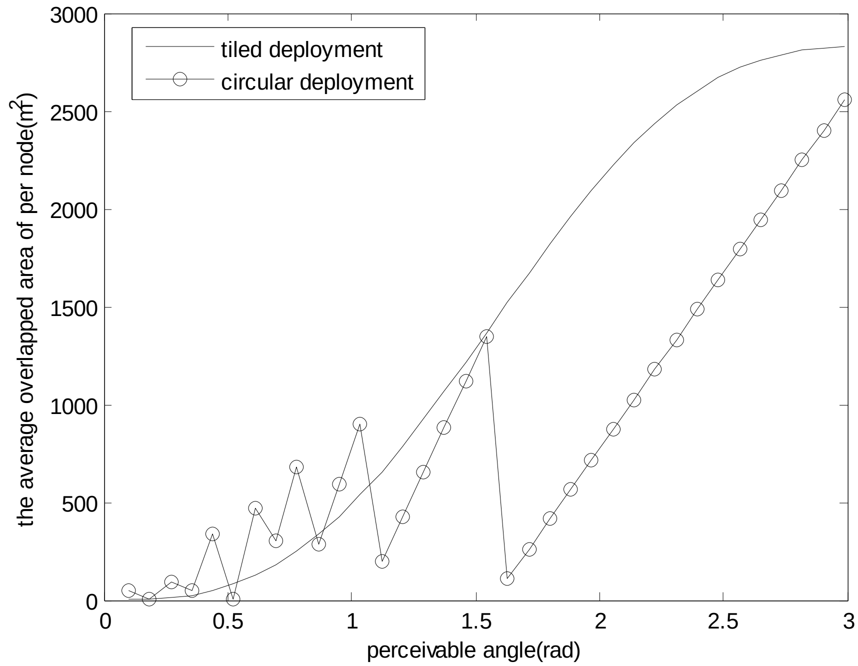
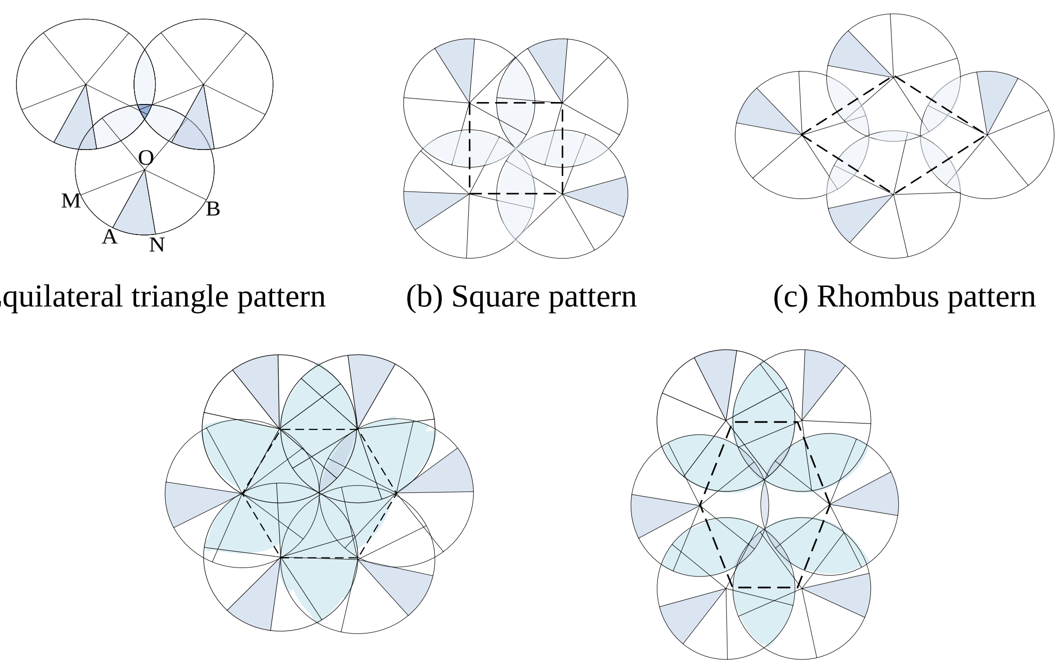


Figure 4. The comparison between circular deployment and tiled deployment.

The normalized coverage algorithm is used to deploy the circle which consists of image sensor nodes. The deployment method is shown in Figure 5.



(a) Equilateral triangle pattern (b) Square pattern (c) Rhombus pattern

(d) Regular hexagon pattern (e) Irregular equilateral hexagon pattern

Figure 5. Specificatious of patterns

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III. COVERAGE ALGORITHM

a. 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 Figure 3 overlap AON.

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

$$S_1 = \frac{1}{2} r_s^2 [n(\theta - \sin\theta)] \qquad (6)$$

where, n is the number of overlapping in a graphical specification; θ is the central angle of overlapping area; r_s node sensing radius.

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

$$S_2 = \frac{1}{2} r_s^2 (\left\lceil \frac{\pi}{\alpha} \right\rceil \times 2\alpha - 2\pi) \qquad (7)$$

All the overlapping coverage area:

$$S = S_1 + N_P \cdot S_2 \qquad (8)$$

where, N_p is 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:

$$\overline{S} = \frac{\frac{S_1}{N_P} + S_2}{\left\lceil \frac{\pi}{\alpha} \right\rceil} \qquad (9)$$

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 Eq. (6).

For the rhombus as shown in Figure 6, the overlapping area is composed of two parts:

$$S_1 = \frac{1}{2} r_s^2 [2(\beta - \sin\beta) + 8(\theta - \sin\theta)] \qquad (10)$$

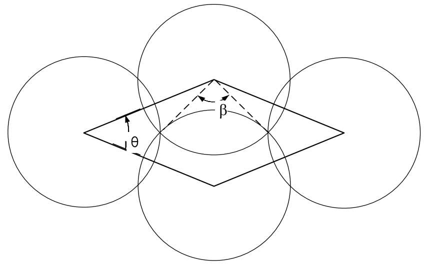


Figure 6. Rhomubus pattern

For the irregular equilateral hexagon, as shown in Figure 7, 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

$$L = \min\left\{2r_s\cos(\frac{\theta}{2}), r_c\right\} \qquad (11)$$

and interior angle is

$$\theta = \pi - 2\arcsin(\frac{r_c}{2r_s}) \qquad (12)$$

where, r_c is the node communication radius.

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

$$x = \mathrm{L} + 2\times\mathrm{L}\times\sin(\theta - \frac{\pi}{2}) \qquad (13)$$

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

$$\cos\frac{\beta}{2} = \frac{\frac{x}{2}}{r_s} \qquad (14)$$

The central angles of the overlapping area are calculated according to

$$\beta = 2\times\arccos(\frac{\frac{x}{2}}{r_s}) \qquad (15)$$

$$\varepsilon = 2(\pi - \theta) - \beta \qquad (16)$$

The overlapping area of irregular equilateral hexagon is:

$$S_1 = \frac{1}{2} r_s^{\ 2} [12(\varepsilon - \sin\varepsilon) + 2(\beta - \sin\beta)] \qquad (17)$$

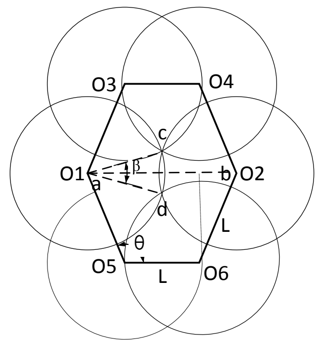


Figure 7. Irregular equilateral hexagon pattern

b.The area overlap rate

When used equilateral triangle, square, rhombus, regular hexagon, irregular equilateral hexagon to deploy, due to the different of the specifications graphics, the overlapping area of the combined round is different. In one combined round, the perceivable angle will also produce overlapping area.

Defined the formation of a specification pattern deployment is used the combined round to finish an equilateral triangle, square, rhombus, regular hexagon and irregular equilateral hexagon. Then, when complete a specification pattern deployment, the total overlapping area than total covers area is deployment area overlap rate:

$$p = \frac{S}{N_P \cdot \gamma} \qquad (18)$$

c.The regulative algorithm of deterministic deployment

In the probability sensing model, to achieve the completely effective perception, single sensor nodes may cannot meet the demand, therefore, needs to increase the nodes to cooperative awareness. In order to get effective quality information of the monitoring area, we set the threshold η, when $p_{\alpha_i} > \eta$, the target is perceived, vice versa, the target is perceived loss. Here η is set to the initial probability p_0[25]:

$$\eta = p_0 = 1 - (1 - \frac{\alpha r_s^2}{lm})^n \qquad (19)$$

where, l、m is respectively the length and width of the monitoring area.

The algorithm is composed of the following steps:

1) According to the method of deterministic deployment to divide grid, lay the nodes to achieve coverage completely;

2) Calculate the number n of sensors in the monitoring region and probability threshold;

3) The initialization of increased node number m=0;

4) Judge whether the minimum probability of each grid is less than the threshold probability η, if there is any numerical less than η: $m = m + 1$,vice versa, jump to 6);

5) Compare the minimum probability of the grid after increase nodes with the probability threshold, if it still less than η, $m = m + 1$, vice versa, jump to 6);

6) Output the total number of the node in the monitoring area $n + m$, and end.

IV. SIMULATION ANALYSIS

a. Experimental condition

In the experiments, the node sensing radius is 30m, the range of communication radius is between 24m to 60m, the uncertain value re is 16m, sensing angle is 60°. A square area of S=1000m×1000m was selected as the experimental scene simulated in Matlab R2013a with $\lambda = 1, \beta = 0.5$.

The number of the nodes according to radius proportion is presented in Figure 8.

The higher probatilistic threshold the better. As can be seen from Figure 9, when $r_c / r_s < 1.224$, the equilateral triangle pattern is the best choice; when $r_c / r_s > 1.224$, the regular hexagon pattern is better.

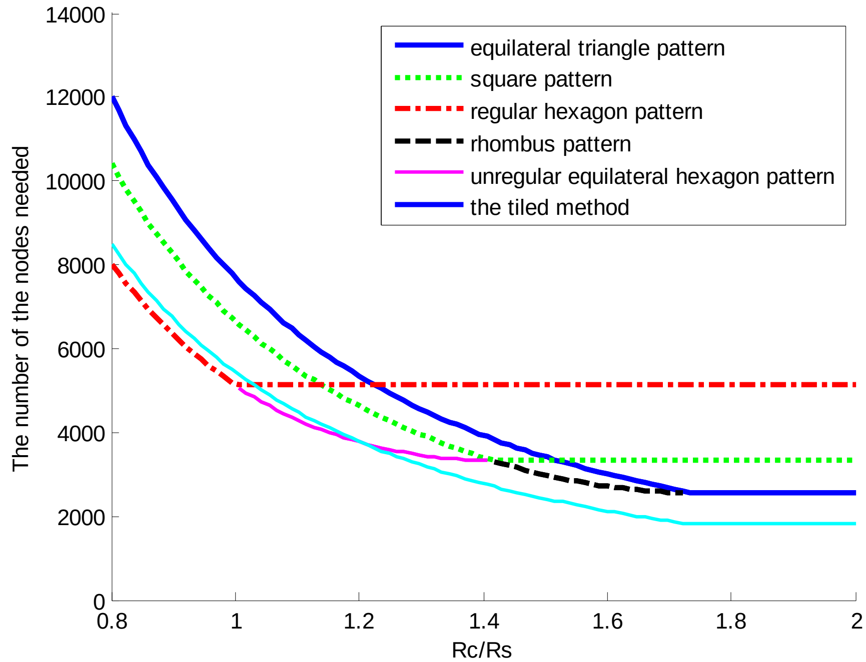


Figure 8. The number of the nodes according to radius proportion

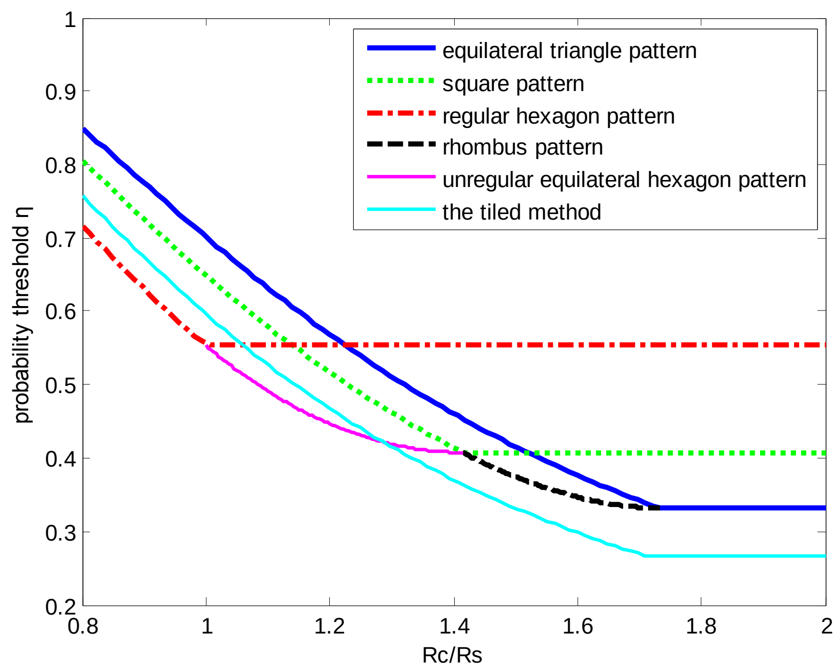


Figure 9. The probatilistic threshold according to radius proportion

The overlapping area in the monitoring area reduces the effective coverage of the nodes, resulting in redundant monitoring, which is a problem that should be avoided in node deployment. But for the perceived probability model, the perceived ability of nodes assumed trends of attenuation from distant to the targets, overlapping coverage generated by independent sensor nodes increases the perceived strength of the target point, and ensures the integrity and validity of data collection in the monitoring area

When two nodes have redundant coverage in the monitoring area, the joint probability density of the overlapping area is:

$$p(x_1, x_2) = p(x_1) \times p(x_2) \quad (20)$$

To make the two nodes do not overlap, satisfy the condition:

$$|x_1 - x_2| \geq 2r_s \quad (21)$$

The overlapping joint probabilities p(x,y) of the two nodes are integrated in the range of formula (21) to compute the overlapping probabilities $P_y(S_y)$:

$$P_y(S_y) = \iint p(x_1, x_2) dx_1 dx_2 \quad (22)$$

Substituting formula (20) and formula (21) into formula (22):

$$P_y(S_y) = \iint p(x_1) p(x_2) dx_1 dx_2 = \int_{-\infty}^{+\infty} p(x_2) dx_2 \int_{x_2 - 2r_s}^{x_2 + 2r_s} p(x_1) dx_1 \quad (23)$$

For the deterministic deployment in the monitoring area, the location of each node is fixed. Therefore, the monitoring probability Py (Sy) of the overlapping area in practical application is:

$$P_y(S_y) = p(x_1) + p(x_2) - p(x_1) \cdot p(x_2) \quad (24)$$

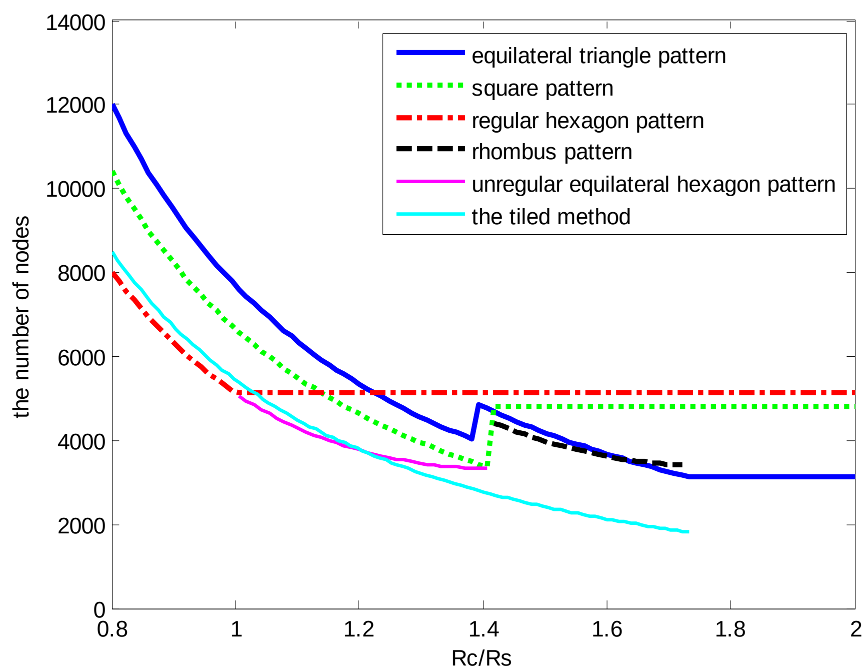


Figure 10. The number of the nodes according to radius proportion

According to the the monitoring probability of the overlapping area and improved deterministic deployment algorithm base on probability model, the number of the nodes which adjusted by probability threshold according to radius proportion shown in Figure 10. When satisfies all the area of monitoring area are perceived and nodes can communicate with each other, $r_c / r_s > 1$, regular hexagon deployment with the minimum number of nodes, $1 < r_c / r_s < 1.205$, the unregular equilateral hexagon deployment with the least number of nodes, $r_c / r_s > 1.205$, the tiled method with the least number of nodes.

Due to the tile deployment does not need to increase the node to ensure coverage. In a specification graphical deployment, the simulation results of using different overlapping averages of a node are illustrated in Figure 11 and the overall deployment are illustrated in Figure 12.

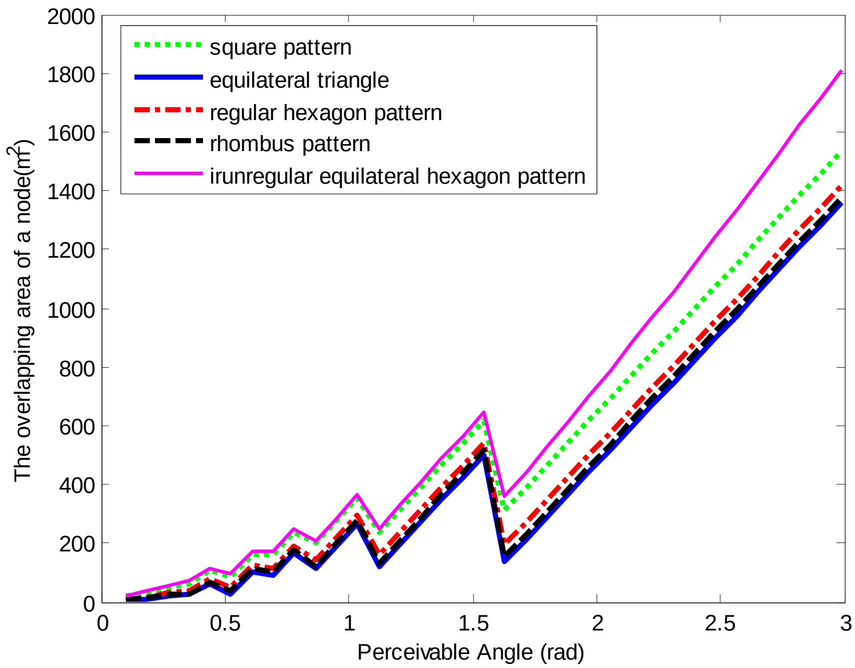


Figure 11. The overlapping area of a node of different specification graphical deloyment

As can be seen from Figure 11, 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 angle is more than 93.4°, five deployment node overlap area increases rapidly.

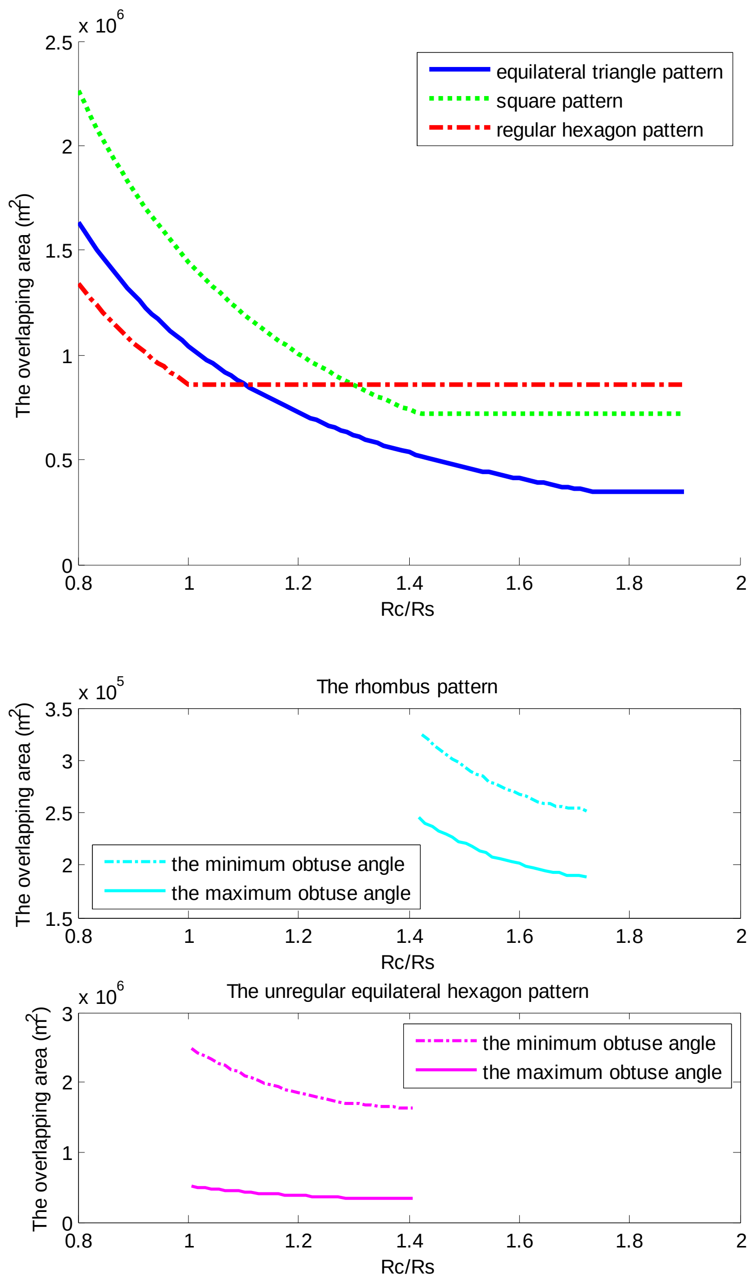
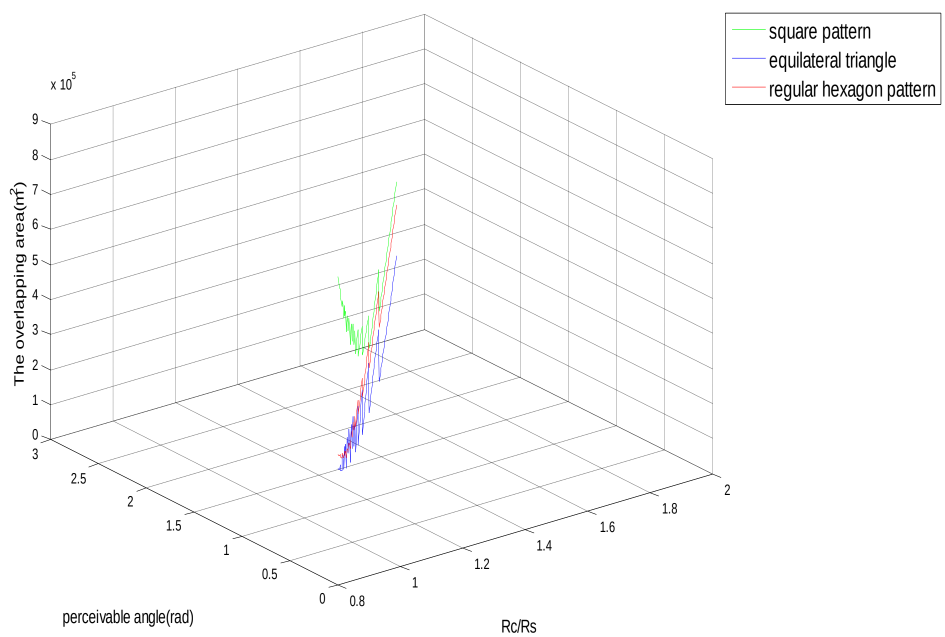


Figure 12. The overlapping area of different specification graphical deloyment

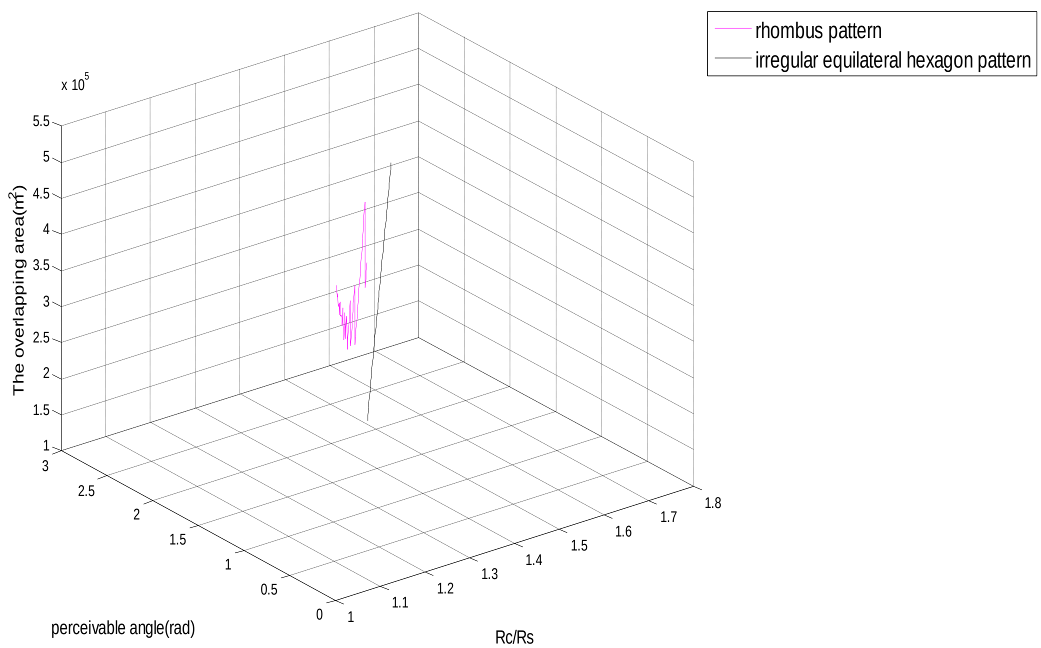
b. Simulation and result

The overlapping area between circle and circle affected by the size of the central angle. As can be seen from Figure 12, for equilateral triangle, square and regular hexagon pattern, under optimal when $r_c / r_s < 1.1$, the overlapping area of regular hexagon deployment is the minimum, when $r_c / r_s > 1.1$, minimal overlap area covered by the equilateral triangle method. For the rhombus and irrunregular equilateral hexagon pattern, overlapping area decreases with increasing radius of communication. Therefore, for the rhombus and irrunregular pattern, respectively study when the angles are different, the overlapping area covered. For rhombus, when an internal angle is equal to 60°, rhombus deployment pattern is equivalent to an equilateral triangle deployment, when four angles are equal, or an internal angle is 90°, rhombus deployment pattern is equal to the square. Therefore divided inside the scope of rhombus, the obtuse angle from the minimum and maximum, the overlapping area of 189000 m^2 to 324300 m^2. For used irrunregular equilateral hexagons to deployment, based on when an internal angle is 120°, the irrunregular equilateral hexagon is equal to the regular hexagon pattern.

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. The simulation results in Figure 13.



(a) Equilateral triangle, square, regular hexagon pattern



(b) Rhombus, irregular equilateral hexagon pattern

Figure 13. The overlapping area of different deloyments

c. Experimental analysis

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 $r_c / r_s < 1.205$, the equilateral triangle deployment mode uses more combined rounds, but the overlapping area in the monitoring area is the least.

V. CONCLUSION AND FURTHER WORK

This paper adopted the deterministic deployment of directional perceived nodes to achieve regional coverage. An improved deterministic deployment algorithm was proposed. The proposed algorithm is able to ensure that the coverage probability in the monitoring area is greater than the probability threshold, thus obtaining better monitoring information. According to the experimental results, the regular hexagon deployment should be chosen for the area where coverage level is less than above; for the area where no clear requirements for coverage level, the deterministic deployment can be chosen according to the specific requirements, in the same monitoring area, when $\sqrt{2} < r_c / r_s < \sqrt{3}$, rhombus deployment is the optimal method.

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REFERENCES

[1] G. J. Fan and Z. W. Guo, “Research progress of node deployment in wireless sensor networks,” Transducer and Microsystem Technologies, April 2012, vol.31, no.4, pp.1-326.

[2] K. Xu, “Device deployment strategies for large-scale wireless sensor networks,” QSpace at Queen’s University, January 2008, pp. 137.

[3] Y. S. He and W. Zhang, “The research on wireless sensor network for landslide monitoring”, International Journal on Smart Sensing and Intelligent Systems, vol. 6, No. 3, June 2013, pp. 870-872.

[4] H. Chen and Z. T. Nan, “Wireless sensor network applications in cold alpine area of west china: Experiences and challenges”, International Journal on Smart Sensing and Intelligent Systems, vol. 6, No. 3, June 2013, pp. 932-950.

[5] F. Zhao and L. Guibas, “Wireless sensor networks-an information processing approach,” Elsevier/Morgan-Kaufman, Amsterdam, April 2004, vol.11, no.2, pp.269-270.

[6] X. Bai, S. Kumar, D. Xuan, Z. Yun and T.H. Lai, “Deploying wireless sensors to achieve both coverage and connectivity,” Proceedings of the 7th ACM international symposium on Mobile ad hoc networking and computing, May 2006, pp. 131-142.

[7] J. Ai and A. A. Abouzeid, “Coverage by directional sensors in randomly deployed wireless sensor networks,” Journal of Combinatorial Optimization, February 2006, vol.11, no.1, pp. 21-41.

[8] X. Han, X. Cao, E. L. Lloyd and C. C. Shen, “Deploying directional sensor networks with guaranteed connectivity and coverage,” IEEE Communications Society Conference on Sensor, June 2008, pp. 153-160.

[9] T. W. Sung, and C. S. Yang, "A Voronoi-based sensor handover protocol for target tracking in distributed visual sensor networks," International Journal of Distributed Sensor Networks, 2014, vol.2014, Article ID.586210, 14 pages.

[10] H. D. Ma and Y. H. Liu,"On coverage problems of directional sensor networks," IEEE Computer Society Press, 2005, vol.3794, pp.721-731.

[11] G. Fusco, and G. Himanshu, "Selection and orientation of directional sensors for coverage maximization," IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks, 2009, pp.1 - 9.

[12] J. Li, R. C. Wang, H. P. Huang, et al. "Coverage control strategy for directional sensor networks, " Journal on Communications, 2011, vol.32, no.8, pp.118-127.

[13] J. Fan, B. H. Zhang, and G. J. Dai, "D3D-MDS: a distributed 3D Localization scheme for an irregular wireless sensor network using Multi-Dimensional Scaling," International Journal of Distributed Sensor Networks, 2015, vol.2015, Article ID.103564, 10 pages.

[14] P. Li, M. H. Wang, and L. Zhao, "New target coverage algorithm in dynamic vision sensor networks," Application Research of Computers, 2010, vol.27, no.5, pp. 1708- 1710.

[15] T. He, C. D. Wu,Y. Z. Zhang. et al. "Design of Probabilistic Sensing Model for Directional Sensor Node," Journal of Jiangnan University:Natural Science Edition, 2012, vol.11, no.4, pp.391-395.

[16] Q. Y. Li, D. Q. Ma, and J. W. Zhang, "Nodes Deployment Algorithm Based on Perceived Probability of Wireless Sensor Network," Computer Measurement and Control, 2014, vol.22, no.002, pp.643-645.

[17] Q. J. Liu, S. Qi,et al. "Transmission power control in wireless sensor networks under the minimum connected average node degree constraint". International Journal on Smart Sensing & Intelligent Systems, 2015, 8(1):801-821.

[18] Z. Y. Sun, H. Z. Wang, W. G. Wu and X. F. Xing, "An enhanced coverage algorithm in wireless sensor network based on probability model," *International Journal of Distributed Sensor Networks*, vol.2015, pp.11, 2015.

[19] H. Ma and Y. Liu, "Correlation based video processing in video sensor networks," International Conference on Wireless Networks, Communications and Mobile Computing, June 2005, vol.2, pp. 987-992.

[20] H. Ma and Y. Liu, "On coverage problems of directional sensor networks," Mobile Adhoc and Sensor Networks, Lecture Notes in Computer Science, December 2005, vol.3794, pp. 721-731.

[21] R. Hekmat, and P. Van Mieghem, "Connectivity in wireless ad-hoc networks with a log-normal radio model," Mobile Networks & Applications, 2006, vol.11, no.3, pp. 351 - 360.

[22] D. Suh, and J. Song, "Determination of Basic Probability Assignment Based on Assessment of Sensor Measurement," International Journal of Control & Automation, 2013, vol.6, no.4, pp.179-186.

[23] H. Zhang and J. C. Hou, “Maintaining sensing coverage and connectivity in large sensor networks,” Ad Hoc & Sensor Wireless Networks, March 2005, vol.1, pp. 89-124.
[24] D. Tao, H. D. Ma, and L. Liu, "Coverage-enhancing algorithm for directional sensor networks," Mobile Ad-hoc and Sensor Networks, 2006, pp.256-267, Springer Berlin Heidelberg.
[25] D. Tao, H. D. Ma, and L. Liu, "Virtual potential field based coverage-enhancing algorithm for directional sensor networks," Ruan Jian Xue Bao(Journal of Software), 2007, vol.18, no.5, pp.1152-1163.