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Study on Optimal Regular Deployment Patterns of Wireless Sensor Network

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Abstract: Wireless sensor network is a popular technology nowadays, having a wide range of application in many fields. The deployment of sensor nodes is a key problem of the technology, it has a great important influence on the network's function and life. The regular deployment is a common one of the node deployment patterns, classical regular deployment includes regular triangle, square, rhombus and equilateral hexagon, but now there is little research into the unregular equilateral hexagon in equilateral hexagon pattern. We investigated the unregular equilateral hexagon in this study. On the basis of the existing research findings, we made derivation to a conclusion that which pattern is the best when the sensing radius and the communication radius have a different proportion and did the simulation.

Keywords: Regular deployment, simulation, unregular equilateral hexagon, wireless sensor network

INTRODUCTION

IT is well known that wireless sensor network technology includes sensor technology, microelectronics technology and wireless communication technology. It is a new technology of achieving and handling information, having a wide application in army, environment and medical treatment fields (Akildiz, 2002). The deployment of the nodes is a key problem in the technology (Khuller, 1998). Classical regular deployment patterns are regular triangle, square, rhombus and equilateral hexagon (Feng and Liu, 2007; Wang *et al*., 2005; Jason, 2003; Xillg *et al*., 2005; Kershner, 1939; Jiang *et al*., 2006). Study by (Wang *et al*., 2005; Jason, 2003; Xillg *et al*., 2005; Kershner, 1939; Jiang *et al*., 2006) have done a deep research into the regular triangle, square, rhombus and regular hexagon, but they didn't consider the unregular equilateral hexagon in equilateral hexagon pattern. On the basis of the existing research findings, we considered the unregular equilateral hexagon pattern and got a conclusion that which pattern is the best when the sensing radius and the communication radius have a different proportion and did the simulation.

METHODOLOGY

Investigation of optimal regular deployment pattern: The quality of the nodes deployment affects the network's function and life directly. Thinking of the wireless sensor network's features and characteristics, when we deploy the nodes, we mainly consider the following three points:

- The achieving information's completeness and accuracy (coverage)
- The information's transmission (connectivity)
- The system's energy consume (life)

To decrease the whole network's cost and energy consume, it should achieve full coverage and connectivity with the least nodes.

Node deployment can be classified in three ways:

- Determined deployment and random deployment
- Static coverage and dynamic coverage
- Area coverage, point coverage and fence coverage

Regular deployment pattern belongs to determined deployment, static coverage and area coverage. Regular deployment pattern has a wide use because of its simplicity and convenience, classical regular deployment pattern includes regular triangle, square, rhombus and equilateral hexagon. The wireless sensor network applied in forestry and agriculture mainly use regular deployment patterns.

Algorithm theory: In this study, the node's sensing ability and communication ability are shown by sensing radius and communication radius, as illustrated in Fig. 1. The distance between the nodes needs to be chosen appropriately to achieve full connectivity under the premise of full coverage. If the distance is too large, it will break the communication. If it is too small, it will

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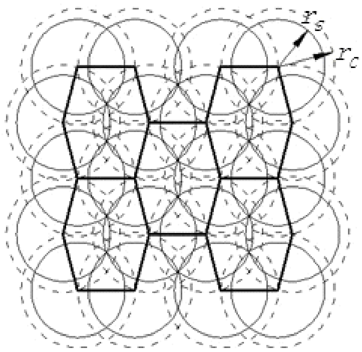

Fig. 1: Unregular equilateral hexagon deployment pattern

Table 1: Optimal regular deployment pattern according to radius proportion (original achievement)

The proportion of sensing radius and communication radius	The optimal deployment pattern
$0 < r_c / r_r \le \frac{1}{2}3^{\frac{3}{4}}$	regular hexagon
$\frac{1}{2}3^{\frac{3}{4}} < r_c / r_s \le \sqrt{2}$	square
$\sqrt{2} < r_c / r_s < \sqrt{3}$	rhombus
$r_c / r_s \ge \sqrt{3}$	regular triangle

decrease the coverage area and the coverage efficiency (Jiang *et al*., 2006). Then the connectivity and coverage problem is simplified to use sensing circles to cover a given area and make sure that they can communicate at the same time. Using circles to cover an area, there must be overlap between them. When the area of the overlap is the smallest, the amount of the used circles is the least.

According to the coverage basic theory, in regular topology, the average area occupied by every node is defined as . It is shown in Formula (1):

$$\lambda = S_P/N_P \times N_n \tag{1}$$

S_P is the area of the regular pattern, N_P denotes the number of nodes that compose a pattern, and N_n denotes the number of pattern blocks that share a node. When λ is larger, the amount of the nodes which needed to cover a same area is fewer.

Original achievement: Xiaole Bai and the others have expounded regular triangle, square, rhombus, regular hexagon, four regular deployment patterns' max λ computation detailedly and got the optimal regular deployment pattern conclusion (Wang *et al*., 2005; Jason, 2003; Xillg *et al*., 2005; Kershner, 1939; Jiang *et al*., 2006) which is shown in Table 1.

The original achievement only considered the regular triangle, square, rhombus and regular hexagon, ignored the unregular equilateral hexagon in equilateral hexagon pattern.

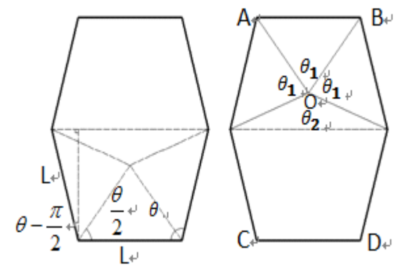

Fig. 2: Unregular equilateral hexagon pattern

Investigation of unregular equilateral hexagon deployment pattern: Unregular equilateral hexagon pattern is shown in Fig. 2.

As in Fig. 2, to achieve full coverage and connectivity at the same time, it is obvious that the length L should equal $\min\left\{2\cos(\frac{\theta}{2})r_s, r_c\right\}$, so the area of the hexagon is

$$S_p = (2\sin(\theta-\frac{\pi}{2})L + L + L) \times \cos(\theta-\frac{\pi}{2})L \tag{2}$$

The unregular equilateral hexagon's λ is

$$\lambda^{UH} = \frac{S_p}{N^p} \times N_n = \frac{\frac{2(\sin(\theta-\frac{\pi}{2})+1)+1\cos(\theta-\frac{\pi}{2})}{6} \times 3}{r_s^2[\sin(\theta-\frac{\pi}{2})+1\cos(\theta-\frac{\pi}{2})(\min\left\{2\cos(\frac{\theta}{2}),\frac{r_C}{r_s}\right\})^2} \tag{3}$$

Assuming $d(o, a) = d(o, b) = d(o, c) = d(o, d) = d$.

To achieve full coverage, we can know $d \le r_S$. To achieve full connectivity, we can know $d(a, b) = d(a, c) = d(b, d) \le r_c$. Let $\angle\ aoc = \theta_1\ \angle\ doc = \theta_2$, so $\theta_2 = 2\pi - 3\theta_1$. $d(a, b) \le r_c$ is equal to $d \le r_c /2y$, in which $y = \sin(\frac{\theta_1}{2})$.

The area of trapezium $abdc$ is $(S = (1/2)\, d^2\, [3\sin(\theta_1) + \sin(\theta_2)]$. Using half-angle formula and triple-angle formula, it can be rewritten as $S = 16d^2y^3(1-y^2)^{\frac{3}{2}}$, in which $0 \le y = \sin(\frac{\theta_1}{2}) \le 1$. We consider two cases for maximizing S while satisfying the coverage and connectivity.

When $r_s \le (r_c/2y)$, only $d \le r_S$ needs to be considered. Now the area s can be seen as the product of two independent functions $f(d) = 16d^2$, $d \le r_S$ $f(y) = y^3(1-y^2)^{\frac{3}{2}}, 0 \le y \le 1$. The function $f(d)$ is maximized when $d = r_s$; because $f(d)$ is a monotonically increasing function on $0 < d \le r_s$. The function $f(y)$ is a concave for $0 \le y \le 1$; achieving its maximum when $y = \frac{\sqrt{2}}{2}$. So $f(y)$ is increasing when $0 \le y \le \frac{\sqrt{2}}{2}$ and decreasing when

$\frac{\sqrt{2}}{2} \leq y \leq 1$. There are two constraints on y: $0 \leq y \leq 1$ and $y \leq r_s /2\ r_s$. Therefore, $f\ (y)$ attains its maximum at $y = \min(\frac{\sqrt{2}}{2}, \frac{r_c}{2r_c})$. Hence, we obtain if $\frac{r_c}{2r_s} \leq \frac{\sqrt{2}}{2}$, s is maximized when $y = r_c/2\ r_s$, and if $\frac{r_c}{2r} \geq \frac{\sqrt{2}}{2}$, s is maximized when $y = \frac{\sqrt{2}}{2}$.

When $r_s \geq / 2y$, only $d \geq r_s / 2y$ need to be considered. Now the area S is $S = 4r_c^2 y(1-y^2)^{\frac{3}{2}}$. $f(y) = y(1-y^2)^{\frac{3}{2}}$, $0 \leq y \leq 1$, the function $f(y)$ is a concave for $0 \leq y \leq 1$; achieving its maximum when $y = 1/2$. So $f(y)$ is increasing when $0 \leq y \leq 1/2$ and decreasing when $1/2 \leq y \leq 1$. There are two constraints on y: $0 \leq y \leq 1$ and $y \geq r_c / 2r_s$. Therefore, $f\ (y)$ attains its maximum at $y = \max(\frac{1}{2}, \frac{r_c}{2r_s})$. Hence, we obtain if $r_c / 2r_s \leq 1/2$, s is maximized when $y = 1/2$, and if $\frac{r_c}{2r} \geq \frac{1}{2}$, s is maximized when $y = r_c / 2r_s$.

Combining the two cases:

- If $r_C / r_s \leq 1$, then when $\theta = 2\pi / 3$, λ^{UH} is the max, equal to regular hexagon model,.
- If $r_C / r_S \geq \sqrt{2}$, then when $\theta = \pi/2$, λ^{UH}, is the max, equal to square model,.
- If $1 < r_C / r_S < \sqrt{2}$, then when $\theta = \pi - 3\arcsin(r_C/2r_s)$, λ^{UH} is the max, $\lambda_{\max}^{UH} = r_C^2\left[\sin(\theta - \frac{\pi}{2}) + 1\right]\cos(\theta - \frac{\pi}{2})$

Optimal regular deployment pattern: Combining the original achievement and the results we get in this study, we can get a final optimal regular deployment pattern conclusion shown in Table 2.

SIMULATION ANALYSIS

To verify the conclusion got in this study, we do the simulation work respectively in Matlab and NS2.

Number simulation based on matlab:
Experimental scenario: A given square area S = 1000×1000 m, the node sensing radius r_s is 30 m, communication radius r_c changes within a certain range: $24\text{m} \leq r_c \leq 57$ m , that is $0.8 \leq r_C/ r_s \leq 1.9$. Use these nodes to cover a field, ignoring the influence of the boundary and compare the number of the nodes needed in different regular deployment patterns. The result got in Matlab is shown in Fig. 3.

Comparing the five regular deployment patterns segmentedly, we can find it is consistent with the conclusion we get in Table 2.

Table 2: Optimal regular deployment pattern according to radius proportion

The proportion of sensing radius and communication radius	The optimal deployment pattern
$0 < r_c / r_s \leq 1$	regular hexagon
$1 < r_c / r_s < \sqrt{2}$	unregular equilateral hexagon (in which, $\theta = \pi - 2\arcsin(r_C/2r_s)$)
$r_c / r_s = \sqrt{2}$	square
$\sqrt{2} < r_c / r_s < \sqrt{3}$	rhombus
$r_c / r_s \geq \sqrt{3}$	regular triangle

θ is marked in Fig. 2

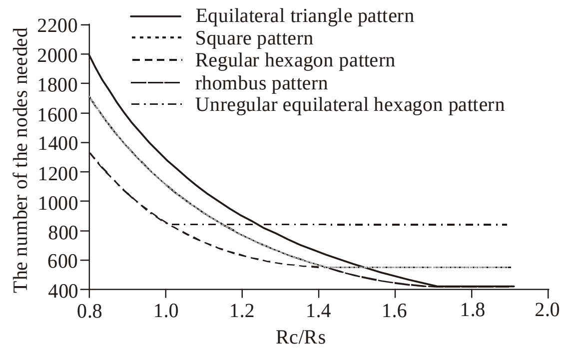

Fig. 3: The number of the nodes according to radius proportion

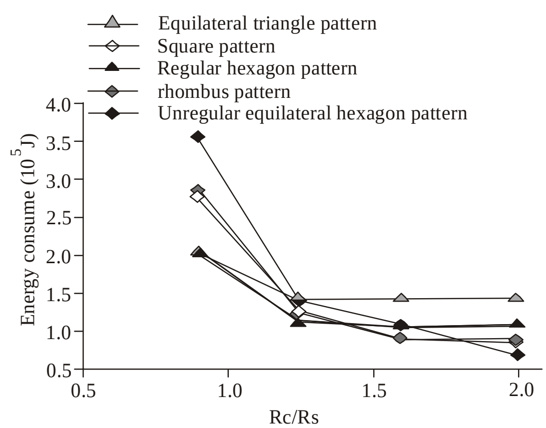

Fig. 4: Energy consume according to radius proportion

Energy simulation based on NS2: NS2 (Network Simulation Version 2) is a source code open network simulation software. It is developed by UC Berkeley at first. It does a strong support to the simulation of wired and wireless network's TCP, route, and multicast agreements.

Experimental scenario: A given square area $S = 1000/\sqrt{20}m \times 1000/\sqrt{20}m = 50000m^2$, the node's sensing radius r_s is 30 m, communication radius r_C = 27, 37.5, 48 and 60 m, respectively. That is r_C / r_s = 0.9, 1.25, 1.6, 2. Use these nodes to cover a field, ignoring the influence of the boundary and compare the energy consume of the nodes needed in different regular deployment patterns. The result got in NS2 is shown in Fig. 4.

Figure 4 shows that the energy consumed in the network is consistent with the number of the nodes needed in it. It proves that the number of the nodes is the key factor of determining the whole network's energy consume. The energy consume is almost proportional to the number of the nodes. Decreasing the number of the nodes will reduce the whole network's energy consume effectively.

CONCLUSION

Wireless sensor network is a new popular technology, having a wide application in army, medical treatment, agriculture and many other fields. The deployment of sensor nodes is a key problem of the technology, it has a great important influence on the network's function and life. This study abstracted sensor node to 0-1 model and considered the coverage, connectivity and energy consume three indexes. On the basis of the original achievement, we did a deep research into the unregular equilateral hexagon, made derivation to a conclusion that which pattern is the best when sensing radius and communication radius have a different proportion and did simulation from number and energy. The achievement in this study offers guidance to the design of the parameters-given wireless sensor network. To the sensor node deployment theory, it has an important reference value.

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