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RESEARCH ARTICLE

LIN Zhi-ting, ZHAO Bao-hua, QU Yu-gui, ZHAI Yu-jia

Algorithm for the placement of nodes for effective coverage

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Abstract An effective method for extending wireless sensor network lifetime is presented for redundancy nodes. Because most of the existing coverage protocols are based on the circular sensing model, this paper discusses how to combine consideration of coverage and connectivity maintenance in a single effective scheduling when the sensing model is not circular. The least redundancy coverage strategy (LRCS) strategy takes the smallest redundant coverage as the criterion whose goal is to maximize the lifetime of the sensor network. The sensor nodes are divided into five statuses: the judgment status, the waiting status, the activity status, the dormancy status and the exhausted status. Simulations show that LRCS outperforms the coverage configuration protocol and is suitable for various situations. It effectively reduces the number of active nodes and extends the lifetime of the sensor network.

Keywords wireless sensor network, coverage, least redundancy

1 Introduction

With the recent advancements in micro electromechanical systems (MEMS) related technology, it has now become feasible to manufacture low power sensors that integrate detection of infrared radiation, heat, sound, vibration, and magnetism together with on-chip intelligence and wireless communication [1]. Sensor networks that consist of thousands of nodes with limited battery power and wireless communication provide great opportunities for monitoring information about a region of interest. It has been an important issue for sensors gathering information in an energy-efficient manner for quite some time.

Generally speaking, coverage problems can be divided into two different situations. One is aimed at optimizing the number of sensors and determining their placement to support controllable sensor networks. The other is often called "The Redundancy Coverage".

Controllable means that the placement of sensor nodes can be controlled. To solve this problem, it is usually supposed that the sensor field is made up of grid points [2, 3]. The proposed algorithms address coverage optimization under the constraints of imprecise detections and terrain properties. On the other hand, the deployment cannot be determined in advance when the environment is unknown or hostile in which case the sensors may be air-dropped from an aircraft or deployed by other means, generally resulting in a random placement [4].

In order to enhance the sensor network robustness and the monitor data accuracy, it usually makes use of the high density deployment. However, since the density of sensor nodes is so high, some region is covered by a set of nodes at the same time, which is often called "The Redundancy Coverage". In recent years, scholars often concentrate on how to construct different sensor groups. Only a group of sensors work at each time. Although achieving energy conservation by scheduling nodes to sleep is not a new approach, the majority of literatures are based on the supposition that sensor sensation model is circular [5]. Obviously in practical application, various sensors cannot be modeled according to the circular sensation model consistently. So, we propose the LRCS.

The LRCS strategy takes the smallest overlap area as the criterion whose goal is to maximize the lifetime of the sensor network. The sensor nodes that cause less overlap area have the priority to turn to be active. Simulations showed that LRCS outperformed coverage configuration protocol and was suitable for various situations. It can decrease the active sensors as far as possible and balance the nodes energy consumption.

The paper is organized as follows. Sect. 1 is the introduction. After introducing two correlative theorems in Sect. 2, Sect. 3 focuses on the details of the LRCS. Our strategy will be compared with the primary algorithms via simulations

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LIN Zhi-ting, ZHAO Bao-hua (✉), QU Yu-gui, ZHAI Yu-jia
Department of Computer Science and Technology,
University of Science and Technology of China,
Hefei 230027, China
E-mail: bhzhao@ustc.edu.cn

and be shown to exhibit excellent performance in Sect. 4. Sect. 5 draws our conclusions.

2 Correlative theorems

In this section, we analyze the relationship between 1-coverage and connectivity in the sensor network. Based on the circular sensation model, Refs. [6–8] have provided geometric analysis of the fundamental relationship. So, in this paper we discuss how to combine consideration of coverage and connectivity maintenance in a single activity scheduling when the sensing model is not circular. We assume that the communication radius is R_c. Let $R_s, R_{s-\min} \le R_s \le R_{s-\max}$ be the sensation range.

Theorem 1 For a set of sensors with arbitrary boundary that at least 1-cover a convex region *A*, the communication graph is connected if $R_c \ge 2R_{s-\max}$.

Proof For any two nodes *u* and *v* in region *A*, let P_{uv} be the line segment joining them. Since region *A* is convex, and P_{uv} remains completely within *A*. Therefore any point $p \in P_{uv}$ is at least 1-covered. Each point $p, p \in P_{uv}$ has a set of one or more closest sensors S_Group. A finite sequence $S_{uv} = S\_\text{Group}_1, S\_\text{Group}_2, \cdots, S\_\text{Group}_n$ can be constructed for contiguous segments $f_1, f_2, \cdots, f_n$ of P_{uv}, where $p \in f_i$ if *p* is covered by the same S_Group_i. Additionally, if there were any two sensors $x \in S\_\text{Group}_i$ and $y \in S\_\text{Group}_{i+1}$, since any point on P_{uv} is at least 1-covered, the maximum distance between *x* and *y* is as follows:

$$|xy|_{\max} = |px|_{\max} + |py|_{\max} = 2R_{s-\max} \quad (1)$$

So when $R_c \ge 2R_{s-\max}$, we can always construct a communication path from *u* to *v* through each combination of node choices in the S_Group. The communication graph of sensors in region *A* is connected.

Therefore under the condition that $R_c \ge 2R_{s-\max}$, a sensor network utilizing LRCS only needs to be configured to guarantee coverage in order to satisfy both coverage and connectivity. In addition, to solve the redundancy coverage, we must reduce the quantity of active nodes. It is claimed that overlap is a better index for measuring power consumption than the number of working sensors [8]. As to be proved in the following lemma, minimizing the overlap value is equivalent to minimizing the number of working sensors in case that all sensors have the same sensing area.

Theorem 2 If all sensor nodes $\{S_1, S_2, \cdots, S_n\}$ a) completely cover a region *R* and b) have the same sensing area (Does not require that the sensation model is the circular), then minimizing the number of working nodes is equivalent to minimizing the overlap of sensing areas of all the nodes.

Proof Let the region that contains *R* and the sensor coverage areas $\{|S_1| \cup |S_2| \cup \cdots \cup |S_n|\}$ to be *E*, where $E \supseteq R$. Let $I_R(x)$ and $I_i(x)$ be the indicator functions.

$$I_R(x) = \begin{cases} 1 & x \in R \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

$$I_i(x) = \begin{cases} 1 & x \in |S_i| \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

With the definition of $I_i(x)$, the overlap at point *x* can be written as:

$$L(x) = \sum_{i=1}^{n} I_i(x) - I_R(x) \quad (4)$$

Hence, the overlap of sensing areas of all the sensor nodes can be written as

$$L = \int_E L(x) = \int_E \Big(\sum_{i=1}^{n} I_i(x) - I_R(x)\Big)\mathrm{d}x$$
$$= \sum_{i=1}^{n} \int_E I_i(x)\mathrm{d}x - |R| = n|S| - |R| \quad (5)$$

Equation (5) states that minimizing the number of working nodes is equivalent to minimizing the redundancy coverage.

Therefore, we can reduce the active nodes by decreasing the overlap area in order to prolong the lifetime of the sensor network.

3 Least redundancy coverage strategy

The LRCS strategy takes the smallest overlap area as the criterion whose goal is to maximize the lifetime of the sensor network. The sensor nodes are divided into five statuses: the judgment status, the waiting status, the activity status, the dormancy status and the exhausted status. The flow chart of the LRCS is outlined below in Fig. 1.

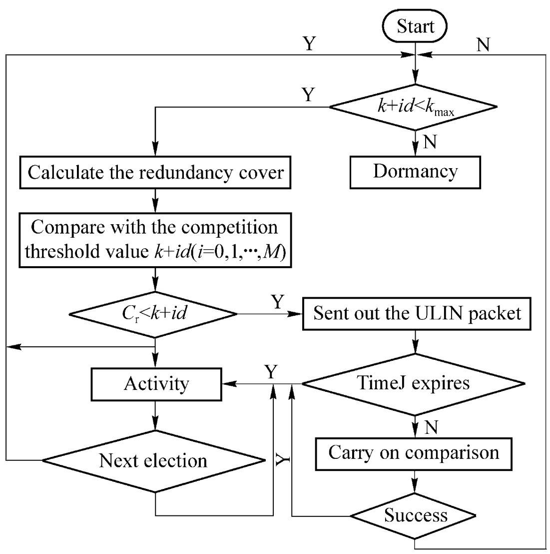

Fig. 1 The flow chart of the LRCS

1) In the judgment status, sensor nodes utilize the remainder of their energy and the coverage situation around them to decide whether to sleep or not. The judgment status splits into 2 (m + 1) time slots. The m value can be chosen according to the tolerable delay. The competition threshold value is increased by degrees. The incremental change is denoted by d as shown in Fig. 2.

Slot 1, threshold k	Wait	Slot 2, threshold $k+d$	Wait	···	Slot m+1, threshold $k+md$	Wait

Fig. 2 The judgment status splits into 2m + 2 time slots and the competition threshold value is increased by degrees

In each slot, the sensor nodes calculate the redundancy cover $C_r = \int_S L(x) \big/ |S|$ and compare it with the competition threshold value $k + id$ (i = 0, 1,···, M). If $C_r < k + id$ then sent out the JOIN packets, which include the sensor node ID, the position information, the cover scope, the remainder energy and so on. Simultaneously, sensor nodes start timer TimeJ and enter the waiting status. Otherwise, repeat the same operation in the next slot until $k + id \geq k_{max}$. It indicates that the sensor nodes are defeated, and should enter the dormancy status. Therefore the sensor nodes that cause less overlap area have the priority to turn to become active.

2) After entering the waiting status, the sensor node turns into the activity status if the timer TimeJ expires. Meanwhile it should transmit the SUCCESS packages to apprize its neighbors to modify the coverage situation. But if the sensor receives neighbors' JOIN packages, it must carry on the comparison according to the received packages and make a decision whether to start or not. The better one can enter the activity status and inform neighbors to adjust the coverage situation. Contrarily, it should return to the judgment status. The neighbors who attempt to turn active carry on the similar operation.

3) When sensor nodes are on their activity status, they should fulfill the responsibility of supervising the environment and would not reenter the judging status until the next initialization.

4) In the case of sleeping status, sensor nodes shut down unnecessary installation for the sake of saving energy and prolonging the lifetime.

5) As to the exhausted status, it will occur when the energy of sensors is used up.

It's obvious that the LRCS can balance the energy consumption among nodes and make for prolonging the whole network's life span by giving the less-overlapping- area node the priority to activate.

4 Simulations and analysis

We present results for a case study carried out by using MATLAB. The simulation is done on a 50 m square sensor field grid with 100, 300, 600, or 900 sensors randomly placed in the sensor filed. The parameters of the coverage strategy are k = 0.2, m = 9, and d = 0.1. Simulation results are shown in Table 1, indicating that the number of active nodes are less when we employed LRCS. It could reduce the extra energy consumption caused by the redundant data and the transmission conflict.

Table 1 Comparison between LRCS and CCP

	Total sensor nodes			
	100	300	600	900
Active LRCS	18.2	18.5	18.8	18.9
Nodes CCP	20.2	20.2	20.4	20.9

In order to test the coverage strategy performance from different points of view, we considered the lifetime of the sensor network. Simulation is carried out for k = 0.2, m = 9, d = 0.1. Figures 3 and 4 compare the lifetime achieved by LRCS and CCP in a 50 m square sensor field with 100 or 300 sensor nodes. It points out that LRCS outperforms CCP by at least 60 % over 90 % coverage. Figure 4 shows that the LRCS can provide over 95 % coverage for about 10 times of the lifetime of a single sensor node.

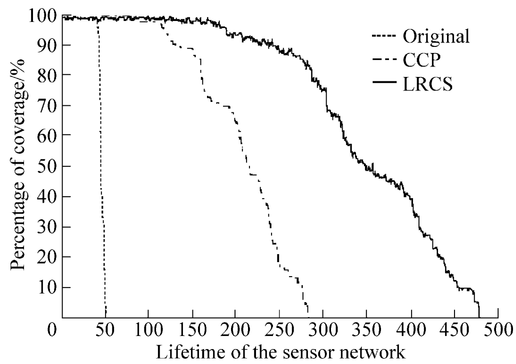

Fig. 3 Comparison of lifetime between LRCS and CCP in a 50 m square sensor field with 100 sensor nodes

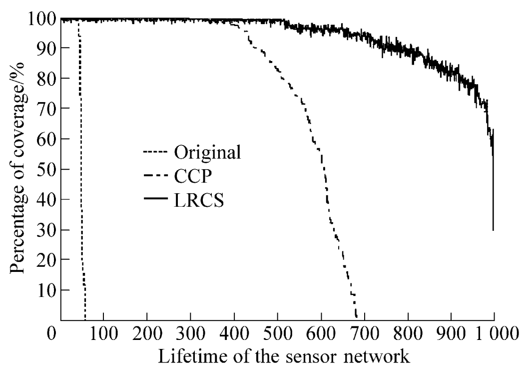

Fig. 4 Comparison of lifetime between LRCS and CCP in a 50 m square sensor field with 300 sensor nodes

Furthermore, we consider an un-circular sensation model in a sensor network of 300 sensor nodes in a 50 m square area, as shown in Fig. 5. LRCS can adapt to various circumstances. It can reduce the number of active nodes and lessen the discrepancy of the coverage situation effectively.

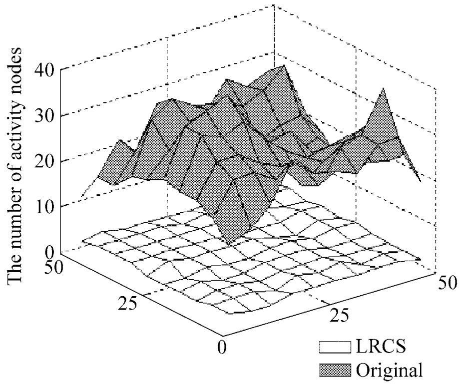

Fig. 5 Performance of LRCS (un-circular sensation model)

5 Conclusions

For improving the network's robustness, we usually deploy large amounts of sensors in the uncontrollable area. This paper focuses on the relationship between coverage and connectivity when given an un-circular model and proposes a more universal strategy LRCS. The sensor nodes that cause less overlap area have the priority to turn to become active. However, when $R_c < 2R_{s-\max}$, more work about coverage is still required.

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References

1. Hill J., Szewczyk R., Woo A. et al, System architecture directions for network sensors, ASPLOS, 2000: 93–104
2. Qu Y. G., Zhai Y. J., Lin Z. T. et al., A novel sensor placement model in wireless sensor network, Journal of Beijing University of Posts and Telecommunications, 2004, 27(6): 1–4 (in Chinese)
3. Dhillon S. S., Chakrabarty K., Sensor placement for effective coverage and surveillance in distributed sensor networks, Proc. of Wireless Communications and Networking, 2003, 3: 1609–1614
4. Heo N., Pramod K., Varshney, Energy-efficient deployment of intelligent mobile sensor networks, IEEE Transactions On Systems, Man, And Cybernetics—Part A: Systems And Humans, 2005, 35(1): 78–92
5. Kannan R., Sitharama S., Iyengar, Game-theoretic models for reliable path-length and energy-constrained routing with data aggregation in wireless sensor networks, Selected Areas in Communications, 2004, 22(6): 1141–1150
6. Di T., Georganas N. D., Connectivity maintenance and coverage preservation in wireless sensor networks, Canadian Conference on Electrical and Computer Engineering, 2004, 2: 1097–1100
7. Wang X. R., Guo L. X., Zhang Y. F. et al., Christopher Gill. Integrated coverage and connectivity configuration in wireless sensor networks, Proc. of the First International Conference on Embedded Networked Sensor Systems, 2003: 28–39
8. Zhang H., Hou J. C., Maintaining sensing coverage and connectivity in large sensor networks, Technical report UIUCDCS-R-2003-2351, 2003