Energy Aware Wireless Sensor Network Low Energy Consumption Full Network Coverage Algorithm

Luo Yonghua¹, Wu Jiawei², Qiu Shangming¹

¹. Department of Computer, Guangdong AIB Polytechnic College,
Guangzhou Guangdong, 510507 China

². College of Computer, South China Normal University,
Guangzhou Guangdong, 510631 China
3158905612@qq.com

Abstract

The energy aware based active node decision and the sensing directions thereof become the research hotspots of DSN (Directional Sensor Network). Therefore, an EACO (Energy aware-based coverage optimal) algorithm is proposed in this paper. Specifically, each cluster head decides the number of the active nodes of the cluster members and the sensing directions thereof according to the coverage area of the sensor nodes and the energy information thereof. Meanwhile, the dormancy mechanism is adopted to minimize the overlapping area among the clusters. The simulation result shows that the proposed EACO algorithm is improved in the aspects of coverage rate and network lifetime.

Keywords: Directional sensor network, Coverage rate; Dormancy; Region optimization; Energy aware

1. Introduction

As a network composed of sensor nodes based on directional sensor model [1], DSN can sense relevant incidents and report relevant data to the Sink. Different from Omni-directional sensor nodes, the directional sensor nodes have limited communication range and directionality, namely the energy aware area is fan-shaped. The directional sensor nodes can effectively employ the space area of the communication channel, thus to reduce radio interference and increase coverage area. Additionally, DSN can improve network performance, thus to be widely applied in various monitoring fields [1-3], such as battlefield reconnaissance and forest field monitoring, wherein the coverage control is the precondition and the basis for the effective implementation of the monitoring task. Meanwhile, EACO algorithm is proposed for the clustered DSN. In EACO algorithm, one CH (Cluster Head) is selected for each cluster, and then CH executes EACO algorithm to determine the active sensor nodes and the sensing directions thereof. CH selects the active node according to the coverage area of the sensor nodes and the rest energy thereof in order not to shorten the whole network lifetime due to the early energy consumption of some sensor nodes. Additionally, EACO algorithm can optimize the coverage area among the clusters, and the dormancy mechanism is introduced therein to minimize the coverage overlapping area among the clusters. EACO algorithm is not simply under distributed control mode or centralized control mode. Actually, each CH intensively controls the cluster members thereof and multiple CHs are distributed in the whole network. The simulation result shows that the proposed EACO algorithm can effectively improve coverage rate and network lifetime.

2. System Model and Hypothesis

N sensor nodes are assumed to be randomly distributed in area Ω , and the sensor nodes transmit the sensing data to the Sink through multi-hop mode. Sensor nodes i ($i=1,2,\dots,N$) are static nodes located at (x_i, y_i) and can acquire the position information of the neighbor nodes. Additionally, all sensor nodes are isomorphic nodes and have same sensing sector S , same sensing radius R_s and same initial energy E_0 . In DSN, the sensor nodes can be switched between active state and dormant state. If the sensor node is under dormant state, then the sensor node will be periodically awakened to communicate with its CH in order to confirm whether there is any new task to be executed.

Specifically, the sensor nodes are assumed to have following characteristics according to the sensing property and the communication property thereof:

- (1) For each sensor node, the sensing sector is $S \geq 2$, the sensing radius is R_s , and the angle of each sector is $\theta_s = \frac{2\pi}{S}$ ($0 < \theta_s < 2\pi$), as shown in Figure 1;
- (2) For each sensor node, the communication radius is R_c ($R_c \geq 2R_s$) [12], and the communication angle is θ_c ($0 \leq \theta_c \leq 2\pi$).

Figure 1. Directional Sensor Node Model

3. EACO Algorithm

EACO algorithm aims at maximizing the coverage area at minimum cost so as to improve network lifetime. In other words, EACO algorithm aims at reducing the coverage area and the overlapping area through an optimal mode. Firstly, each CH intensively controls the cluster members thereof and meanwhile determines the satisfactory sensor nodes are the active nodes and the sensing sectors thereof. Secondly, the dormancy strategy is adopted to disable the nodes generating coverage overlapping area in order to reduce the overlapping area among the clusters. Additionally, CH also collects and processes data packets and transmits the same to the Sink. Next, EACO algorithm will be specifically described.

3.1. Selection of Active Node

Each CH determines the state (active or dormant) of the cluster member node. Specifically, the member set in CH is assumed as C_{ch} , the active sensor node set is assumed as A_{ch} of which the initial value is null. When CH decides to set the state of sensor node i as active state and meanwhile specifies the sensing sector thereof, then sensor node i will be moved from C_{ch} to A_{ch} , namely $A_{ch} = A_{ch} \cup \langle i, s \rangle$, wherein s represents

the sensing sector of sensor node i . Next, the specific selection process will be described.

3.1.1. Sensor Node with Non-Overlapping Coverage Area: CH selects the nodes with non-overlapping sensing area to enter active state. However, it is very difficult to find the completely non-overlapping sector in a dense area. Therefore, the overlapping area threshold value is defined as α , and if the overlapping sensing area is less than α , then the node concerned will be included in active node set A_{ch} , as shown in Formula (1).

$$A_{ch} = A_{ch} \cup \{i, s\} | \text{overlap}(i, j, s) = 0 \quad (1)$$

Wherein $\text{overlap}(i, j, s)$ represents whether sensor nodes i and j are overlapped with each other in sector s . If the overlapping sensing area is less than α , then $\text{overlap}(i, j, s) = 0$ is true; or else, $\text{overlap}(i, j, s)$ is equal to 1. In fact, if Euclidean distance $D(i, j)$ between two sensor nodes i and j is less than their sensing radiuses, namely $D(i, j) \leq 2R_s$, then their sensing sectors must be overlapped with each other. Therefore, the following formula can be obtained on the basis of considering the overlapping area threshold value α :

$$\text{overlap}(i, j, s) = \begin{cases} 0, & \text{if } D(i, j) \leq 2R_s \text{ \& } AO(i, j, s) \leq \alpha \\ 1, & \text{other} \end{cases} \quad (2)$$

Wherein $AO(i, j, s)$ represents the overlapping area of sensor nodes i and j in sector S_s .

3.1.2. Sensor Node with Size of Overlapping Area More Than α

According to Formula (1), after the non-overlapping sensor nodes are removed from C_{ch} , the rest sensor nodes in C_{ch} are the sensor nodes with the size of the overlapping area more than α . Next, EACO algorithm will select some nodes from the rest nodes according to rest energy E_{res} and non-overlapping area $ANO_{i,s}$ and then add them to A_{ch} . Therefore, another index $AE_{i,s}$ is defined to comprehensively present rest energy E_{res} and the non-overlapping sensing area $ANO_{i,s}$ information.

$$AE_{i,s} = \omega_1 \times \frac{ANO_{i,s}}{\frac{\theta_s}{2} R_s^2} + \omega_2 \times \frac{E_{i,s}}{E_0} \quad (3)$$

Wherein θ_s represents sensing sector angle, $\frac{\theta_s}{2} R_s^2$ represents the total size of the area covered by sensing sector s , E_0 represents the initial energy of the node, ω_1 and ω_2 are the weight factors.

$ANO_{i,s}$ represents the size of the non-overlapping area covered by sensor node i in sector s , as shown in Formula (4).

$$ANO_{i,s} = A_{i,s} - AO_{i,j,s} \quad (4)$$

Wherein $A_{i,s}$ represents the size of the coverage area of sensor node i in sector s .

Notably, $AE_{i,s}$ in Formula (3) is the linear combination of $\frac{ANO_{i,s}}{\frac{\theta_s}{2} R_s^2}$ and $\frac{E_{i,s}}{E_0}$, and this

index is favorable for selecting the sensor nodes with sufficient rest energy or with large non-overlapping area to enter A_{ch} , thus to improve the network lifetime and reduce coverage overlap.

After $AE_{i,s}$ calculation, $AE_{i,s}$ is adopted to sort the nodes in C_{ch} by a descending order in order to form sequence list γ . Afterwards, it is necessary to judge whether the first sensor node in γ can meet Formula (5); if yes, this node will be included in A_{ch} . Other nodes will be also judged as above till the communication area of CH is completely covered, namely:

$$AO_{i,j,s} \leq \delta \quad (5)$$

Wherein δ is the threshold value which is exponentially increased in each round of operation.

3.1.3. Whether CH Area is Completely Covered: Once a new active node is selected, CH needs to judge whether the communication area is completely covered; if yes, the algorithm is terminated. The total size of the communication area of CH is CA_{ch} :

$$CA_{ch} = \frac{\theta_c}{2} R_c^2 \quad (6)$$

When sensor node i and the sensing sector thereof are added to active sensor node set A_{ch} at each time, the non-overlapping area of sensor node i will be added to the coverage area of CH, namely: the coverage area of CH is expanded, as shown in Formula (7).

$$A_{ch}^{cur} = A_{ch}^{prev} + ANO_{i,s} \quad (7)$$

Wherein $ANO_{i,s}$ represents the size of the non-overlapping area covered by sensor node i in sector s , A_{ch}^{prev} represents the coverage area of sensor node i before being added in A_{ch} , and A_{ch}^{prev} represents the coverage area of sensor node i after being added in A_{ch} . Once a new node is added in A_{ch} , Formula (7) will be updated till Formula (8) can be met.

$$A_{ch}^{prev} \leq \omega \times A_{ch} \quad (8)$$

Wherein ω is the weight value ($\omega \in (0,1]$) and depends on the expected coverage proportion of CH.

The flow chart of the active node selection algorithm is as shown in Figure 1.

Figure 2. Algorithm 1: Selection of Active Nodes of Cluster Members

3.2. Calculation of Coverage Overlapping Area and Non-Overlapping Area

Algorithm 1 is required to calculate the size of coverage overlapping area and non-overlapping area sensed thereby, so the calculation of coverage overlapping area and non-overlapping area will be described in this section.

If the coverage area of a sensor node is not overlapped with that of any other node, then the size of the coverage area of the sensor node is calculated as follows:

$$A = \frac{\theta_s}{2} R_s^2 \quad (9)$$

If the coverage areas of two sensor nodes are overlapped with each other, then the overlapping area shall be calculated according to the three conditions as shown in Figure 3, wherein the overlapping area is represented by black oblique lines. As shown in Figure 3(a), the overlapping area is surrounded by three straight lines and the size thereof is calculated as follows:

$$A = \sqrt{s(s-a)(s-b)(s-c)} \quad (10)$$

$$\text{Wherein } s = \frac{a+b+c}{2}.$$

As shown in Figure 3(b), the overlapping area is surrounded by two straight lines and one arc, and the size thereof is calculated as follows:

$$A = \frac{ab}{2} \left[\theta - \tan^{-1} \left(\frac{(b-a)\sin(2\theta)}{(b+a) + (b-a)\cos(2\theta)} \right) \right] \quad (11)$$

As shown in Figure 3(c), the overlapping area is surrounded by one straight line and one arc, and the size thereof is calculated as follows:

$$A = \frac{R^2}{2} (\theta - \sin \theta) \quad (12)$$

Figure 3. Area of Overlapping Area

After overlapping area calculation, the proportion $\eta_{i,j}^s$ of the overlapping area in the whole coverage area can be calculated as follows:

$$\eta_{i,j}^s = \frac{A_{i,j}}{A_i} \times 100\% \quad (13)$$

Wherein A_i represents the total size of the coverage area of sensor node i , $A_{i,j}$ represents the size of the overlapping area covered by sensor nodes i and j .

Sensor node i may have overlap with more than one sensor nodes in the coverage area thereof, and the total overlapping area is calculated as follows:

$$AO_{i,j,s} = \sum_{i=1}^{N_{ol}} \eta_{i,j}^s \quad (14)$$

Wherein N_{OL} represents the number of sensor nodes with overlap in the coverage area of sensor node i .

3.3. Minimization of Coverage Overlap among Clusters

Algorithm 1 is mainly used to maximize the coverage area in the cluster and minimize the coverage overlapping area. However, the cluster may have coverage overlap with neighbor clusters. Therefore, the minimization of the overlapping area among the cluster will be discussed in this section.

After active node confirmation, CH_k will communicate with active node members AC_i to obtain their positions and meanwhile communicate with neighbor CH. Afterwards, CH_k will decide which member nodes need to enter dormant state. Specifically, CH_k firstly selects the nodes with coverage overlapping area more than threshold value β , and then includes these nodes in NC_k and sorts them by a descending order.

After NC_k confirmation, CH_k selects one CH_l from NC_k and then establishes set SC_k according to Formula (15):

$$AO_{k,l,s} \neq 0, \forall k \in A_{ch}(k), \forall l \in A_{ch}(l) \quad (15)$$

Wherein $A_{ch}(k)$ and $A_{ch}(l)$ respectively represent the active node sets of CH_k and CH_l . SC_k is sorted by a descending order according to the overlapping quantity. If the first sensor node $\langle i, x \rangle$ is removed from the active node set, then CH_k will confirm whether the communication area is covered. If the communication area is completely covered, then CH_k will send one message to CH_l to inquire whether CH_l is willing to make node i in dormant state; If CH_k receives the confirmation message replied by CH_l , then CH_k will remove $\langle i, x \rangle$ from active node set AC_i and make it enter dormant state.

4. System Simulation and Performance Analysis

4.1. Simulation Environment and Performance Index

Network simulation software NS-3 is adopted to establish the simulation platform, and the sensor nodes are uniformly distributed in the range of $1000m \times 1000m$, and the specific simulation parameters are as shown in Table 1. Additionally, each experiment is independently and repeatedly carried out, and the mean values are taken as the final data.

Table 1. Simulation Parameters

Parameter	Value
Simulation Area	$1000m \times 1000m$
Number of Sensor Nodes	200 ~ 1000
Number of Sensing Sectors S	2 ~ 6
Communication Transmission Range Rc	100m
Sensing Transmission Range Rs	50m
Initial Energy E0	5J
Simulation Time	1000s

Coverage rate and network lifetime are taken as the algorithm performance evaluation indexes. Specifically, the coverage rate refers to the proportion of the coverage area in the total area, and higher coverage rate indicates better performance of DSN. Network lifetime refers to the time difference between the sensor node deployment and the failure of the first node in DSN.

4.2. Simulation Result and Analysis

In order to more comprehensively analyze the performance of the proposed EACO algorithm, OSECRE [9] and IDA [10] are simulated at the same time and are compared with EACO algorithm.

4.2.1. Change of Number of Sensor Nodes: Firstly, in order to check the influence of the number of sensor nodes on algorithm performance, the number of sensor nodes is increased from 200 to 1000, and the number of the sectors of each sensor node is $S_s=4$. The simulation results are as shown in Figures 4 and 5.

Figure 4. Change of Coverage Rate along with Number of Sensor Nodes

As shown in Figure 4, the coverage rate is increased along with the increase of the number of sensor nodes. Compared with OSRCEA and IDA, the proposed EACO algorithm has improved coverage rate, wherein the reason is as follows: in EACO algorithm, CH as the controller comprehensively decides the sensor node state, but in OSRCEA and IDA, each sensor node only makes its own decision, without any coordination with other sensor nodes, thus to be difficult to realize optimal coverage rate.

Figure 5 shows the change curve of network lifetime along with the number of sensor nodes. According to Figure 5, the network lifetime is increased with the increase of the number of sensor nodes. Compared with OSRCEA, the proposed EACO algorithm can effectively improve network lifetime averagely by 40%. Such improvement is attributed to the introduction of cluster algorithm in EACO algorithm for network overhead reduction. Additionally, the rest energy information of the sensor node is also considered for the active node selection, but the energy level of the sensor node is not consider in IDA or OSRCEA.

Figure 5. Change Curve of Network Lifetime along with Number of Sensor Nodes

4.2.2. Influence of Number of Sectors on System Performance

In this experiment, the number of sectors is changed from 2 to 6, and the number of sensor nodes is 600. The simulation results are as shown in Figures 6 and 7.

The change curves of the coverage rates of the three schemes along with the number of sectors are as shown in Figure 7. The more the number of the sensing sectors, the smaller the coverage angle of each sector. Meanwhile, the coverage rate is reduced along with the increase of the number of sectors, and this is also verified by the data in Figure 6. Additionally, according to Figure 6, compared with OSRCEA and IDA, the proposed EACO algorithm has improved coverage rate.

Figure 6. Change of Coverage Rate along with Number of Sectors

Figure 7 shows the change of the network lifetime along with the number of sensing sectors. According to Figure 7, the network lifetime is reduced along with the increase of the number of sectors, because the number of the active nodes is increased along with the increase of the number of sectors and this can reduce network lifetime. In conclusion, the proposed EACO algorithm is obviously superior to OSRCEA and IDA in the aspect of network lifetime.

Figure 7. Change Curve of Network Lifetime along with Number of Sectors

5. Conclusion

In allusion to clustered DSN coverage problem, EACO algorithm is proposed in this paper. EACO algorithm aims at maximizing the coverage area and minimizing the coverage overlapping area. Specifically, CH intensively controls the cluster members, and then Algorithm 1 is adopted to select the number of the active nodes and the sensing sector directions. Meanwhile, the energy of the sensor node and the coverage overlapping information are considered during the selection process, thus to realize maximum coverage at minimum cost. Additionally, the dormancy mechanism is introduced in EACO algorithm to reduce the coverage overlapping area among the clusters, and some nodes are selected to enter the dormant state so as to reduce the size of the coverage overlapping area. The simulation result shows that the proposed EACO algorithm can effectively improve network lifetime and coverage rate.

References

- [1] Guanxiong Liu, Yishuang Geng, Kaveh Pahlavan, Effects of calibration RFID tags on performance of inertial navigation in indoor environment, 2015 International Conference on Computing, Networking and Communications (ICNC), Feb. (2015).
- [2] Jie He, Yishuang Geng, Yadong Wan, Shen Li, Kaveh Pahlavan, A cyber physical test-bed for virtualization of RF access environment for body sensor network, IEEE Sensor Journal, 13(10), 3826-3836, Oct. (2013).
- [3] Wenhua Huang, Yishuang Geng, Identification Method of Attack Path Based on Immune Intrusion Detection, Journal of Networks, 9(4), 964-971, Jan. (2014).
- [4] Guanqun Bao, Liang Mi, Yishuang Geng, Mingda Zhou, Kaveh Pahlavan, A video-based speed estimation technique for localizing the wireless capsule endoscope inside gastrointestinal tract, 2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Aug. (2014).
- [5] Degui Zeng, Yishuang Geng, Content distribution mechanism in mobile P2P network, Journal of Networks, 9(5), 1229-1236, Jan. (2014).
- [6] Mingda Zhou, Guanqun Bao, Yishuang Geng, Bader Alkandari, Xiaoxi Li, Polyp detection and radius measurement in small intestine using video capsule endoscopy, 2014 7th International Conference on Biomedical Engineering and Informatics (BMEI), Oct. (2014).
- [7] Wang, Ke. "Using Simulation to Explore Distributed Key-Value Stores for Exascale System Services." 2nd Greater Chicago Area System Research Workshop (GCASR). (2013).
- [8] Yi Wang, Yu Su, Gagan Agrawal. A Novel Approach for Approximate Aggregations Over Arrays. In Proceedings of the 27th international conference on scientific and statistical database management, ACM, (2015).
- [9] Zhihan Lv, Alaa Halawani, Shengzhong Feng, Shafiq ur Rehman, Haibo Li. Touch-less Interactive Augmented Reality Game on Vision Based Wearable Device. Personal and Ubiquitous Computing. (2015).

- [10] Jiachen Yang, Shudong He, Yancong Lin, Zhihan Lv. Multimedia cloud transmission and storage system based on internet of things. Multimedia Tools and Applications. **(2016)**.
- [11] Yu Su. In-situ bitmaps generation and efficient data analysis based on bitmaps. In Proceedings of the 24th International Symposium on High-Performance Parallel and Distributed Computing, pp. 61-72. ACM, **(2015)**.
- [12] Dingde Jiang, Xu Ying, Yang Han, Zhihan Lv. Collaborative Multi-hop Routing in Cognitive Wireless Networks. Wireless Personal Communications. **(2015)**.

Authors

Luo Yonghua. Luo Yonghua received his master of engineering degree in computer software and theory from South China Normal University in Guangzhou, China. He is currently a lecturer in the the Department of Computer Science in Guangdong AIB Polytechnic College. His research interest is mainly in the area of web applications, Computer Software and next-generation networks. he has published several research papers in scholarly journals in the above research areas and has write several books.