Journal of Information Hiding and Multimedia Signal Processing ©2017 ISSN 2073-4212
Ubiquitous International Volume **8**, Number **2**, March **2017**

Uneven Clustering and Data Transmission Strategy for Energy Hole Problem in Wireless Sensor Networks

Jian-Po Li and Zi-Qi Dong

School of Information Engineering
Northeast Electric Power University
Jilin, China
jianpoli@163.com; 841928477@qq.com

Received October 2016; revised February, 2017

Abstract. *Energy hole is one of the key problems in wireless sensor networks (WSN). An Uneven Clustering and Data Transmission Strategy (UCDTS) for the energy hole problem in WSN is proposed. Firstly, the algorithm reduces energy consumption by decreasing the iteration number and selects the optimal cluster heads by considering the speed of energy consumption and the distance between nodes and base stations. Secondly, more reasonable uneven clustering algorithm is proposed to reduce the energy consumption during data collection period by considering node density. Thirdly, the concept of discrete degree of dead node is proposed, which can make the dead nodes discretized in data transmission strategy. The simulation results show that, when the maximum cluster radius* $R_{\max} = 50m$, *the factor weight* $\alpha = 0.4$, *the adjusting coefficient of cluster radius* $\eta = 0.7$, *the algorithm achieves the optimal performance. Compared with LEACH, LEACH-E, UCRA, and UCS, the proposed algorithm prolongs the network lifetime by 3.6%, 19.6%, 125% and 136% separately. At the same time, it also avoids partly the generation of energy hole.*

Keywords: Wireless sensor networks; Routing algorithm; Energy hole; Uneven clustering

1. Introduction.

Wireless sensor networks (WSN) typically consist of a large number of energy-constrained sensor nodes with limited onboard battery resources. The nodes' energy is difficult to renew [1]. Therefore, energy optimization is a critical issue in the design of WSN [2, 3]. In WSN, nodes usually use multi-hop way to forward data to the base station. The nodes that are closer to the base station not only need to send their own data but also to undertake the task of data forwarding. Eventually, the energy of nodes around the base station is exhausting prematurely and the energy hole is formed. Then the nodes which are far away from the base station cannot transmit their data to the base station.

The main methods to solve the energy hole problem include the adjustable transmission power algorithm, the node non-uniform deployment strategy, and hierarchical routing protocol algorithm. The algorithm based on adjustable transmission power avoids the energy hole by adjusting the communication power. In order to achieve life maximization of sensor networks, the ant-based heuristic algorithm (ASTRL) addresses the optimal transmission range assignment [4]. The short-trip moving scheme in ant colony optimization (ACO) decreases algorithm complexity and improves convergence speed [5]. Reference [6] studies the optimization problems for network lifetime maximization (NLM) and energy consumption minimization (ECM).

Besides, some specific non-uniform node deployment algorithms are proposed. The novel sensor redistribution algorithm eliminates the energy hole problem in mobile sensor network [7]. The proposed solution outperforms others in terms of coverage rate, average moving distance, residual energy, and total energy consumption. An off-line centralized algorithm to compute the theoretically optimal track is proposed [8]. It calculates energy consumption of each node when the base station is set at any point in the network through theoretical analysis. By introducing the concept of equivalent sensing radius, a novel algorithm for density control to achieve balanced energy consumption per node is proposed [9]. Different from other methods, a new pixel-based transmission mechanism is adopted to reduce the duplication of the same messages [10]. It investigates the problem of uniform node distribution and energy hole. The algorithm derives the principle of non-uniform node distribution to ensure energy balancing. Reference [11] proposes a NNDC algorithm, which divides the network into some rings, and then makes an analysis and calculation on nodes' energy consumption in each ring of the network. Reference [12] studies the performance optimization of four protocols. They are LEACH [13] (Low Energy Adaptive Clustering Hierarchy), MLEACH (Multi-hop LEACH), HEED (Hybrid Energy Efficient Distributed Clustering Approach) [14], and UCR (Unequal Cluster based Routing) [15]. However, "Hot spots" problem is very easy to generate energy hole under the uniform distribution of nodes. If the multi-hop network adopts uniform clustering, there is as high as 90% of the energy is wasted in the network.

The effect of these current strategies to solve the energy hole is not very ideal. The routing protocol is only based on the cluster structure optimization. These algorithms do not directly solve the energy hole problem [16, 17]. In this paper, we propose a non-uniform clustering and data transmission strategy for WSN. The rest of this paper is organized as follows. In Section II, we present an uneven clustering strategy for WSN. In Section III, some data transmission strategy to avoid energy hole are introduced. Section IV shows the simulation and numerical analysis. Final conclusion remarks are made in section V.

2. The Uneven Clustering Strategy for WSN.

The operation of hierarchical routing for WSN can be divided into set-up phase and steady-state phase. In this paper, we propose firstly an Uneven Clustering Strategy (UCS) to reduce the energy consumption of the network by selecting the optimal cluster head and reasonable cluster radius.

2.1. The calculation of optimal number of cluster head.

In [18], we proposes an uneven clustering routing algorithm (UCRA) by taking into account the calculation of optimal cluster number, cluster head selection, cluster radius calculation. The optimal cluster number k can be obtained as:

$$k = \left\lceil \sqrt{\frac{\varepsilon_{fs} \cdot M^2 \cdot N}{2\pi f_{agg} \cdot \left[\varepsilon_{mp} \cdot E\left(d_{toBS}^4\right) + E_{elec}\right]}} \right\rceil \tag{1}$$

where M^2 stands for $M \times M$ random distributed area for nodes, N is the node number, E_{elec} represents the energy consumption of the transceiver circuit that receive or transmit 1bit data, ε_{fs} and ε_{mp} are proportional constants of the energy consumption for the transmit amplifier in free space channel model and in multipath fading channel model, d_{toBS} is the distance between node and base station, $E\left(d_{toBS}^4\right)$ represents the expected value of d_{toBS}^4. $\lceil a \rceil$ denotes the smallest integer which is greater than or equal to the argument a, f_{agg} is fusion rate.

2.2. **Optimal cluster head selection.** The election method of cluster heads based on probability iteration takes into account the energy, node density, speed of energy consumption, and other factors. They make the algorithm more reasonable and extend the network lifetime effectively. However, in the cluster head election process, at least 5 to 15 iterations are used to select cluster heads. The nodes need to broadcast messages for many times. Too many iterations will lead to more energy consumption. If the optimal cluster head is not elected in 15 iterations, the network will not continue to conduct iterative competition. The temporary cluster head elected in the fifteenth competition iteration will be directly elected as the final cluster head.

To solve the above problem, we propose a cluster head election method based on optimal factors. The algorithm is based on residual energy, distance between node and base station, and speed of energy consumption. The node with more energy and closer to the base station will be elected as a candidate cluster head, which will avoid the cluster head node premature death and energy hole problem.

Define the parameter f_1 and f_2 as

$$f_1 = \frac{E_{residual}}{E_{\max}} \cdot \frac{E_{avecons}}{E_{consume}} \tag{2}$$

$$f_2 = 1 - \frac{d_{toBS}}{d_{toBS\_MAX}} \tag{3}$$

The final influence factor is expressed as

$$Factor = \alpha \cdot f_1 + (1 - \alpha) \cdot f_2 \tag{4}$$

where α is a constant coefficient which will be demonstrated in Section IV.

The fast energy consumption will cause the cluster head node die prematurely and become a failed node. If many nodes in the same area fail, the energy hole will produce. So the energy consumption rate factor $E_{avecons}/E_{consume}$ is introduced. It shows the ratio of the average energy consumption of network and the energy consumption of each node. The more the node energy consumption is, the smaller $\frac{E_{avecons}}{E_{consume}}$ is. The influence factor f_1 in next round will decrease. In addition, the distance between node and base station also has an effect to $Factor$. The node should have larger influence factor f_2 to be cluster head when it is near to base station. Because the node near to the base station not only collects data but also transfer data, which will speed up the energy consumption.

2.3. **Cluster radius calculation.** The size of cluster close to base station should be smaller than the size of cluster far away from the base station. Thereby the energy consumption of cluster head, which is close to base station, to handle the data in the cluster is reduced. More energy is used for the inter-cluster communication.

In UCRA [18], R_L is uniform cluster radius in clustering process. It is unreasonable to control the uneven degree by the listed parameters. The new algorithm use $R_{\max}$, the maximum radius of the clusters, to replace R_L to reduce the quality of isolated nodes. On the other hand, the value of η and $1 - \eta$ is from 0 to 1. Through improving the control parameters, the proportion of node degree is increased. Accordingly, the new cluster radius can be calculated as

$$R_{factor} = \left(1 + \frac{d_{toBS} - E\left(d_{toBS}\right)}{\eta \cdot \left(d_{toBS\_MAX} - d_{toBS\_MIN}\right)}\right) \cdot \left(1 - \frac{N_{NN}}{(1-\eta) \cdot N_A \cdot R_{\max}}\right) \cdot R_{\max} \tag{5}$$

The larger $R_{\max}$ is, the larger the cluster radius is. The larger the node degree is, the smaller the cluster radius is. η will be demonstrated in the Section IV.

2.4. **Node clustering.** Once receiving ADV, each non-cluster head node determines its cluster for this round by choosing the cluster head that requires the minimum communication energy. Those nodes which can't receive message from the cluster head will become isolated nodes.

After each node having selected the cluster it belongs to, it must inform the cluster head node that it will be a member of the cluster. Each node transmits a join-request message (Join-REQ) to the chosen cluster head. The cluster head node sets up a TDMA schedule and transmits this schedule to the nodes in its cluster. After the TDMA schedule has been known by all nodes in the cluster, the set-up phase is completed and the steady-state operation will begin.

2.5. **Data transmission.** Once the cluster head receives all the data, it performs data aggregation to enhance the common signal and reduces the uncorrelated noise among the signals. The resultant data are sent to the base station by routing path or directly. In [18], the isolated node can determine whether to join near cluster according to the cost of joining near cluster.

3. **Data Transmission Strategy to Avoid Energy Hole.** At present, the hierarchical routing protocol is used to solve the energy hole problem in WSN. These algorithms mainly focus on the optimization of cluster structure, selection of optimal cluster head, calculation of the optimal cluster number, and reasonable cluster distribution. Less work has been done in data transmission period.

In the whole lifetime of WSNs, if the effect of energy hole on WSNs is reduced to a minimum, it can effectively improve the utilization rate and lifetime of WSNs. The location of the dead node should be random and discrete distribution. The randomization and discretization of the dead node will balance the energy consumption for the whole network and avoid the generation of energy hole.

3.1. **Discrete degree of dead node.** In this paper, we propose a new concept, the discrete degree of dead node, to describe the distribution of dead node. The discrete degree of dead node reflects the minimum distance between dead nodes, the average distance between dead nodes, and the number of dead nodes. It can be calculated as

$$f_{Dnd} = a\sqrt{d_{DM}} + b\log_5 d_{DA} + c/N_{Death} \tag{6}$$

where, d_{DM} is the minimum distance between dead nodes, d_{DA} is the average distance between dead nodes, N_{Death} is the number of dead nodes, a, b, c are constant coefficients, $0 < f_{Dnd} < 1$. The bigger the discrete degree of dead node is, the better the network performance is.

The discrete degree of dead node, f_{Dnd} is directly proportional to d_{DM} and d_{DA}, which ensure the randomization and discretization of dead node. f_{Dnd} is inversely proportional to N_{Death}, which can decrease the number of dead node. It is an efficient way to avoid or minimize energy hole to increase the discrete degree of dead node. In each round, the detailed method to determine the discrete degree of dead node is as follows.

i. If the minimum distance between dead nodes is relatively large, the number of dead nodes is small, and the average distance between dead nodes is very large, the effect of distribution of dead nodes is good.
ii. If the minimum distance between dead nodes is relatively small, the number of dead nodes is large, even if the average distance between dead nodes is very large, the effect of distribution of dead nodes is bad.

iii. If the minimum distance between dead nodes is small, the number of dead nodes is small, the average distance between dead nodes is larger, the effect of distribution of dead nodes is good.
iv. If the minimum distance between dead nodes is relatively large, the average distance between dead nodes is relatively small, the number of dead nodes is small, the effect of distribution of dead nodes is good.
v. If the minimum distance between dead nodes is small, the average distance between dead nodes is small, the number of dead nodes is large, the effect of distribution of dead nodes is bad.
vi. If the number of dead nodes has exceeded the number of survival nodes, the effect of distribution of dead nodes is poor.

3.2. **Data transmission strategy.** According to the characteristics of energy hole, we propose the following strategy combined with the routing protocol proposed above to solve the problem of energy hole.

i. Strategy for cluster head adjustment

After cluster head adjustment and reconstruction, the nodes that have been elected as cluster head nodes will not become cluster head nodes again in the next five rounds. In the clustering process, the elected cluster head node will broadcast message, and show that it is elected cluster head. Its' neighbor nodes receive this election message, and remember its' ID. Each node has a neighbor list and in which the elected cluster head node ID is record. In the next round of competition to select cluster head, the elected cluster head node will be removed in the list of neighbor nodes to avoid electing repeatedly.

ii. Sleeping-in-turn strategy for low energy nodes

When the node residual energy is less than 20%, the nodes will sleep in turn to prolong the lifetime of the whole network.

iii. Sleeping strategy for nodes at energy hole edge

In each round of node broadcast, the node will remember the information of surrounding nodes in previous several rounds. If the node cannot receive the information of the surrounding nodes in the past 2-3 round, the nodes are considered that they died. If there are more than three dead nodes, the energy hole is formed. The survival nodes near the energy hole will sleep and transmit data in turn.

iv. Cluster head avoiding strategy for low energy node

In this strategy, the nodes with less energy will not be elected cluster heads.

4. **Simulation and Numerical Analysis.** In NS2, we distribute randomly 100 nodes in the area of $100 \times 100m^2$ (in formula (1), $N = 100$, $M = 100m$). The initial energy of all the sensor nodes is equal. In (4), $\alpha = 0.4$. In (5), $R_{\max} = 50$, $\eta = 0.7$. In (6), $a = 0.03$, $b = 0.13$, $c = 0.84$. The proposed UCDTS in this paper is compared with LEACH [13], LEACH-E [19], UCS, and UCRA [18].

Figure 1 shows the influence of α in formula (4) on the average number of alive nodes in UCS. The simulation result shows that, when $\alpha = 0.4$, the time that the first node dies has been delayed by 4.6% and 60% respectively compared with $\alpha = 0.6$ and $\alpha = 0.5$, and the network lifetime has been prolonged by 0.8% and 6.7% respectively. In addition, compared with $\alpha = 0.2$ and $\alpha = 0.3$, although the network lifetime is shorter, but the time that the first node dies has been delayed by 350% and 125% respectively. So $\alpha = 0.4$ is the optimal value in formula (4).

Figure 2 shows the influence of $R_{\max}$ in formula (5) on the average number of alive nodes in UCS. When $R_{\max} = 50$, the time that the first node dies has been delayed by 309%

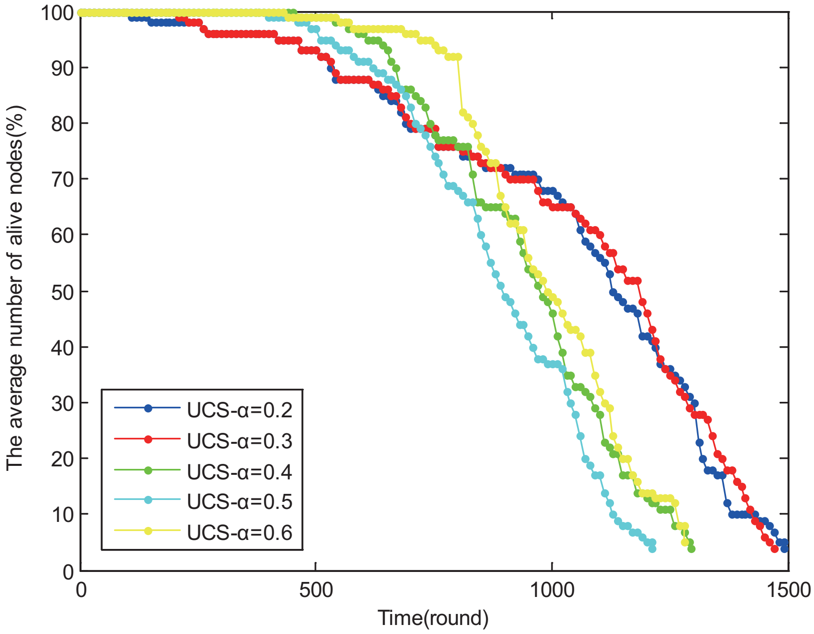

FIGURE 1. The average number of alive nodes by changing the α in UCS

and 25% compared with $R_{\max} = 35$ and $R_{\max} = 40$. The time that the first node dies is almost same compared with $R_{\max} = 55$, but the network lifetime has been prolonged by more than 3.2%. So $R_{\max} = 50$ is the most optimal parameter.

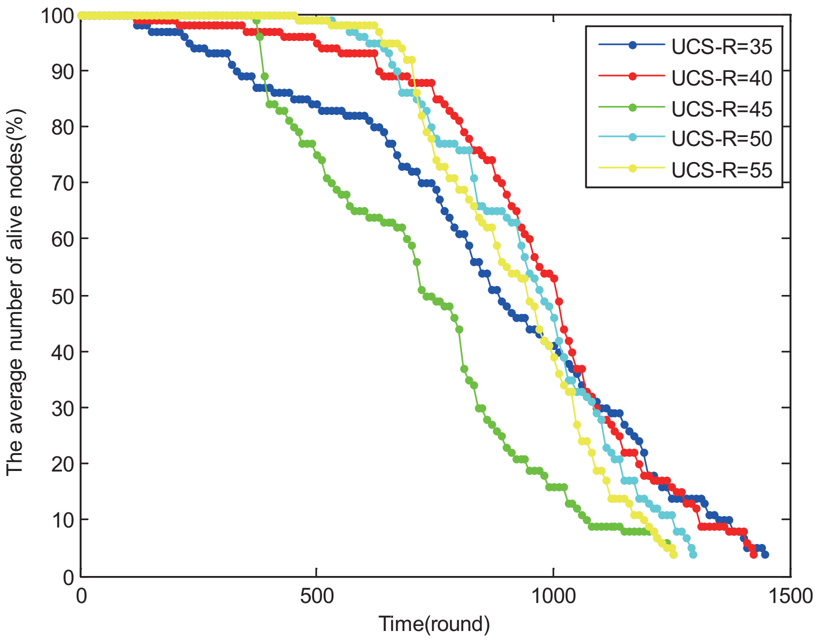

FIGURE 2. The average number of alive nodes by changing the $R_{\max}$ in UCS

Figure 3 shows the influence of η in formula (5) on the average number of alive nodes in UCS. When $\eta = 0.7$, the time that the first node dies has been delayed by 350%, 125%, 15.3%, 4.6% compared with $\eta = 0.5$, $\eta = 0.6$, $\eta = 0.8$, $\eta = 0.9$ respectively.

Figure 4 shows the average number of alive nodes for different algorithms. The simulation result shows , compared with LEACH, LEACH-E, UCRA, and UCS, the time that

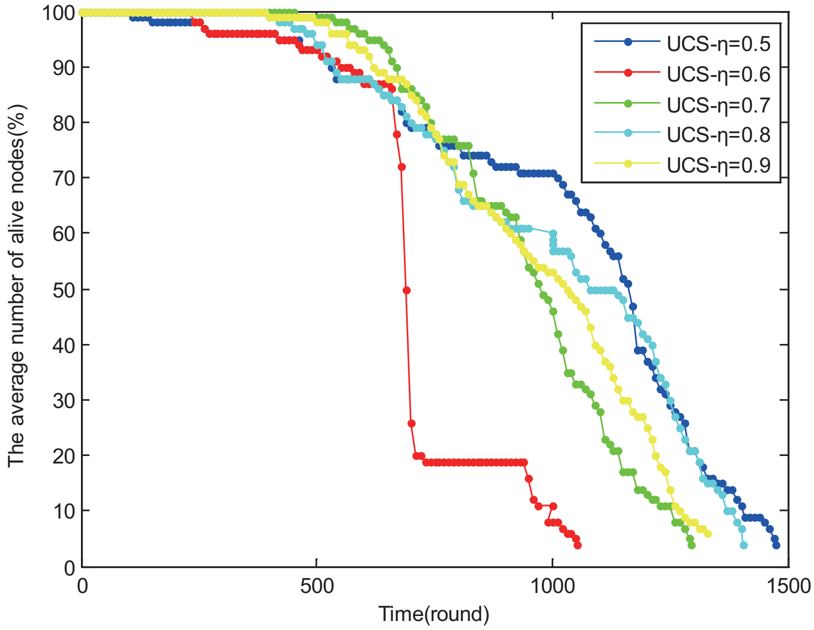

FIGURE 3. The average number of alive nodes by changing the η in UCS

the first node dies has been delayed about 333%, 550%, 93%, and 13% separately. The whole network lifetime is prolonged by about 122%, 71.5%, 19.6%, and 3.6% respectively.

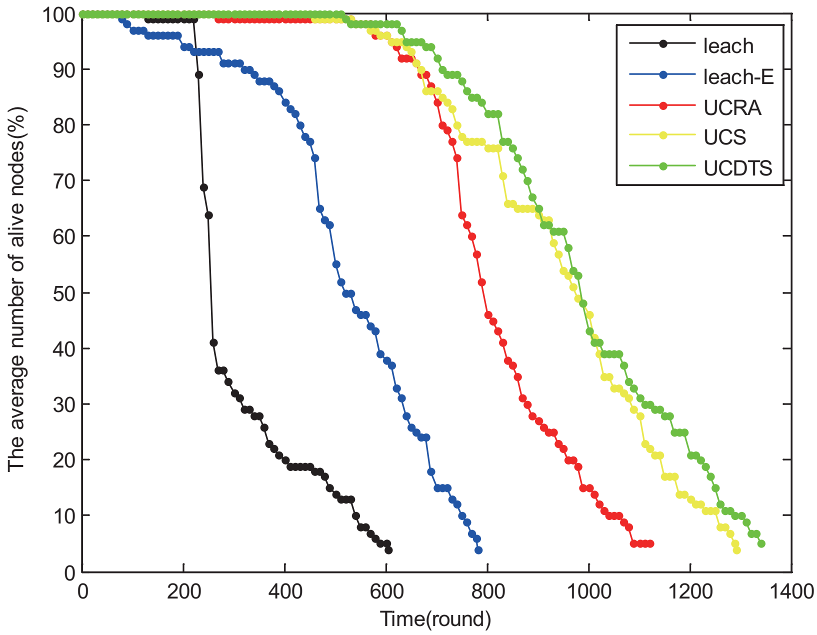

FIGURE 4. The average number of alive nodes for different algorithms

Figure 5 shows the average distance between dead nodes for different algorithms. After the 600th round, the average distance between dead nodes for UCDTS is longer than that for other algorithms, except very few rounds. Before the 600th round, the average distance between dead nodes is shorter than that for other algorithms, because there are a large number of dead nodes in each round for the above algorithms mentioned. It results in the longer average distance between dead nodes than that for UCDTS. So UCDTS has very good performance to avoid the formation of energy hole.

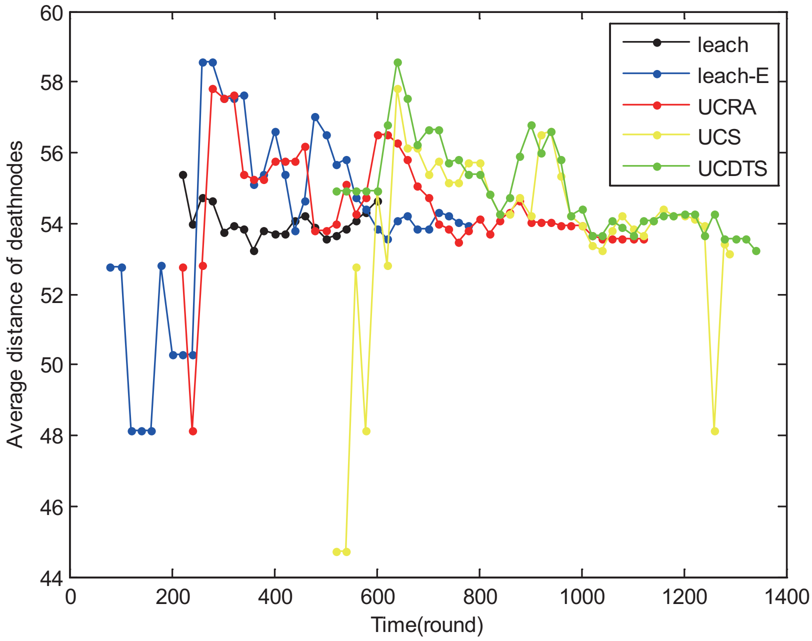

Figure 5. The average distance between dead nodes for different algorithms

Figure 6 shows the minimum distance between dead nodes for different algorithms. UCDTS delays the time that the first node dies. The minimum distance between dead nodes for UCDTS in each round is longer than that for LEACH, LEACH-E, UCRA, and UCS. UCDTS can effectively avoid the dead node distance too close and the generation of energy hole.

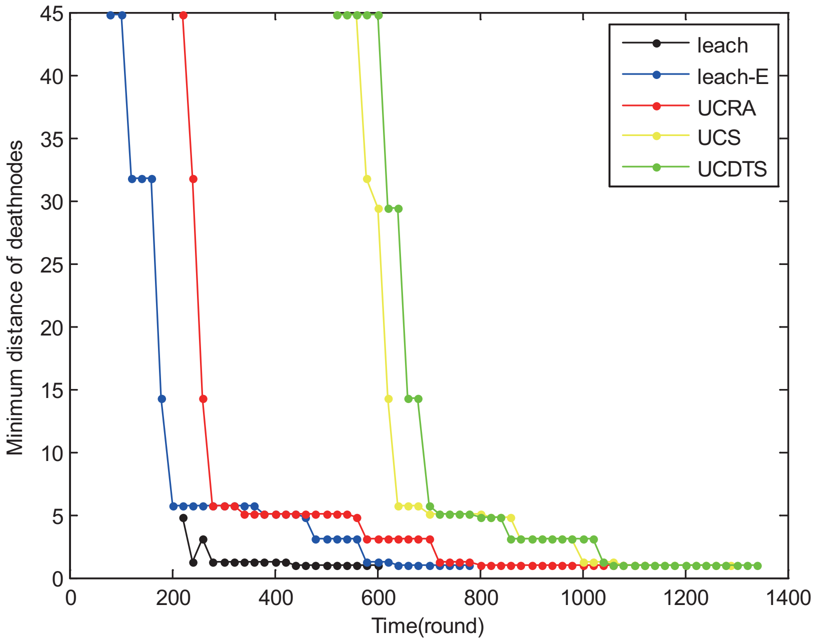

Figure 6. The minimum distance between dead nodes for different algorithms

Figure 7 shows the discrete degree of dead node for different algorithms. At the beginning of network, the maximum of the discrete degree of dead node is about 0.94 for UCDTS. In each ground, the discrete degree of dead node for UCDTS is higher than that for LEACH, LEACH-E, UCRA, and UCS. It shows that UCDTS can effectively avoid the dead node distance too close and the generation of energy hole.

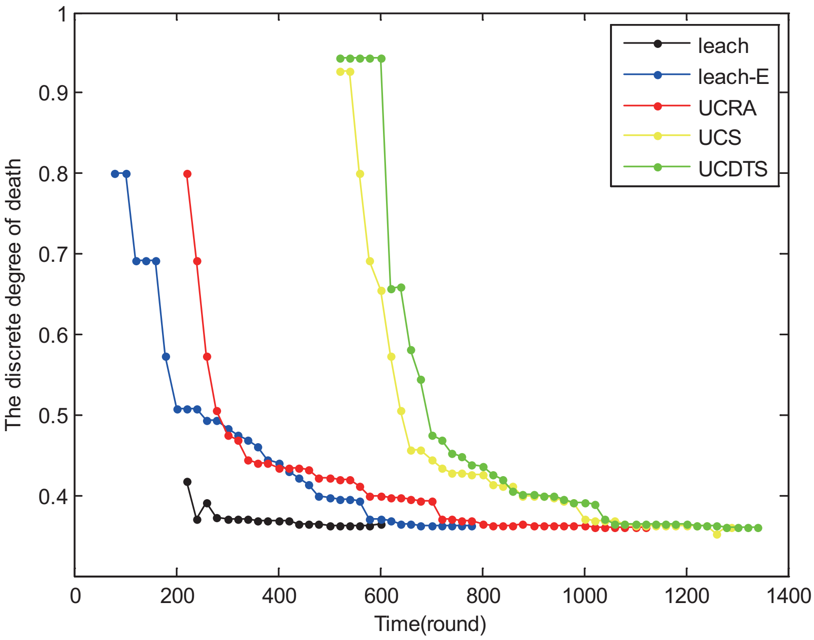

FIGURE 7. The discrete degree of dead node for different algorithms

5. **Conclusion.** In this paper, an uneven clustering and data transmission strategy is proposed to avoid energy hole in WSN. During the period of cluster head election, UCDTS reduces energy consumption through decreasing the iteration number. During the period of uneven clustering, UCDTS introduces the node density and the distance from node to the base station. It makes the uneven clustering more reasonable and reduces the energy consumption in cluster data collection. During the period of data transmission, it makes the dead nodes discretized through cluster head adjusting and sleeping-in-turn strategy. Simulation experiments show that, when the maximum cluster radius $R_{\max} = 50$, the weight of the election factor $\alpha = 0.4$, the adjustment coefficient of the cluster radius $\eta = 0.7$, discrete degree adjustment coefficient of dead node $a = 0.03$, $b = 0.13$, $c = 0.84$, the algorithm achieves optimal performance. Compared with LEACH, LEACH-E, UCRA, and UCS, the proposed UCDTS has its superiority in terms of network lifetime, the number of alive nodes, and the total energy consumption. At the same time, it can avoid the energy hole effectively.

Acknowledgments. The work in this paper was partly supported by National Natural Science Foundation of China (No. 61501106), Science and Technology Foundation of Jilin Province (No. 20150520097JH).

REFERENCES

[1] Z. Teng, M. Xu, and L. Zhang, Nodes deployment in wireless sensor networks based on improved reliability virtual force algorithm, *Journal of Northeast Dianli University*, vol. 36, no.2, pp.86-89, 2016.
[2] Z. Teng, X. Zhang, The layout optimization of WSN based on inertia weight shuffled frog leaping algorithm, *Journal of Northeast Dianli University*, vol. 35, no.6, pp. 66-69, 2015.
[3] L. Savita and W. Gayatri, A Survey on Energy Efficient Routing Protocols in Wireless Sensor Network, *In Proceedings of ICCCNT*, 2013.

[4] M. Liu and C. Song, Ant-based transmission range assignment scheme for energy hole problem in wireless sensor networks, *International Journal of Distributed Sensor Networks*, vol. 2012, no. 8, pp. 385-391, 2012.

[5] X. Liu, A novel transmission range adjustment strategy for energy hole avoiding in wireless sensor networks, *Journal of Network & Computer Applications*, vol. 67, pp. 43-52, 2016.

[6] Z. Sun, C. Zhou, Adaptive cluster algorithm in WSN based on energy and distance, *Journal of Northeast Dianli University*, vol. 36, no.1, pp.82-86, 2016.

[7] J. Jia, X. Wu, J. Chen, and X. Wang, Exploiting sensor redistribution for eliminating the energy hole problem in mobile sensor networks, *Eurasip Journal on Wireless Communications & Networking*, vol. 2012, no. 1, pp. 1-11, 2012.

[8] Q. H. Li, Q. M. Pan, and F. P. Xie, A novel sink mobility off-line algorithm for avoiding energy hole in wireless sensor network, *Journal of Computers*, vol. 9, no. 6, 2014.

[9] J. Jia, J. Chen, and X. Wang, Energy-balanced density control to avoid energy hole for wireless sensor networks, *International Journal of Distributed Sensor Networks*, vol. 2012, no. 1, pp. 104-107, 2012.

[10] S. Halder, A. Ghosal, and S. D. Bit, A pre-determined node deployment strategy to prolong network lifetime in wireless sensor network, *Computer Communications*, vol. 34, no. 11, pp. 1294-1306, 2011.

[11] L. Tang, P. Jian, X. Wang, J. Yang, and B. Guo, Research on the energy hole problem based on non-uniform node distribution for wireless sensor networks, *Ksii Transactions on Internet & Information Systems*, vol. 6, no. 9, pp. 2017-2036, 2012.

[12] A. F. Liu, P. H. Zhang, and Z. G. Chen, Theoretical analysis of the lifetime and energy hole in cluster based wireless sensor networks, *Journal of Parallel & Distributed Computing*, vol. 71, no. 10, pp. 1327-1355, 2011.

[13] R. H. Wendi, C. Anantha, and B. Hari, Energy-efficient communication protocol for wireless microsensor networks, *In Proceedings of HICSS*, 2000.

[14] Y. Ossama and F. Sonia, HEED: A hybrid energy-efficient distributed clustering approach for ad-hoc sensor networks, *IEEE Transactions on Mobile Computing*, vol. 3, no. 4, pp. 366-379, 2004.

[15] S. Stanislava and B. H. Wendi, Prolonging the lifetime of wireless sensor networks via unequal clustering, In *Proceedings of IPDPS*, 2005.

[16] F. Chang and H. Huang, "A survey on intelligent sensor network and its applications, *Journal of Network Intelligence*, vol. 1, no. 1, pp. 1-15, 2016.

[17] T. T. Nguyen, T. K. Dao, M. F. Horng, and C. S. Shieh, An energy-based cluster head selection algorithm to support long-lifetime in wireless sensor networks, *Journal of Network Intelligence*, vol. 1, no. 1, pp. 23-37, 2016.

[18] J. Li and J. Y. H, Uneven Clustering Routing Algorithm Based on Optimal Clustering for Wireless Sensor Networks, *Journal of Communication*s, vol. 11, no.2, pp. 132-142, 2016.

[19] W. B. Heinzelman, A. P. Chandrakasan, and H. Balakrishnan, An application-specific protocol architecture for wireless microsensor networks, *IEEE Transactions on Wireless Communications*, vol.1, no. 4, pp. 660-670, 2002.