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DK-LEACH: An Optimized Cluster Structure Routing Method Based on LEACH in Wireless Sensor Networks

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Abstract Low-Energy Adaptive Clustering Hierarchy (LEACH) is one of the clustering routing protocols for communication in Wireless Sensor Networks (WSNs). It is based on the assumption that each sensor nodes contain equal amount of energy which is not valid in real scenarios, or the sensor nodes are almost spaced evenly. This paper presents an optimized cluster structure routing method called Dynamic K value LEACH (DK-LEACH), which aims at reducing energy consumption within the uneven energy distributed WSNs. DK-LEACH considers the energy factor of Cluster Heads (CHs) in the phase of clusters formation. Furthermore, the distance between CHs and non-CHs nodes is calculated out, and the proportion of this distance and surplus energy of CHs is adjusted dynamically based on the density of node distribution. Then, the most suitable CHs are chosen by non-CHs to form clusters, which balance energy depletion of CHs effectively. Simulation results show that the proposed method performs better than LEACH in terms of energy saving and prolongs the network lifetime, the survival rate of nodes improves 8.75% at least compared with LEACH.

Keywords Wireless sensor networks · Optimized cluster structure · DK-LEACH · Balance energy depletion

1 Introduction

Wireless sensor networks (WSNs) are composed of a large number of static or offset sensors, which exist by the way of self-organization and multi-hop. Sensors in WSNs perceive, gather, handle and transport information of perceived object in network coverage area by collaborative approach. And the gathering data are sent to the Base Station (BS) at

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last [1]. Currently, WSNs has been widely applied in military, aviation, medical treatment, environment monitoring and so on. With the development of it, the energy efficiency is emerging as a premier research topic [2, 3]. Many kinds of algorithms are proposed to save energy of networks.

Low-Energy Adaptive Clustering Hierarchy (LEACH) is proposed to improve the network lifetime firstly. Compared to the planar multi-hop routing protocols and static stratified algorithms, it prolongs the network lifetime to 15% [4, 5]. But the drawbacks of centralized energy consumption and the inadaptability in uneven energy distributed WSNs also exist for LEACH protocol. In order to ameliorate these shortcomings, lots of research has been expanded, such as LEACH-R, V-LEACH, DAIC, EEC-SCH, DB-LEACH and CBR-Mobile are proposed and so on [6–10]. For Distance Aware Intelligent Clustering protocol (DAIC), all the nodes in network are divided into two layers based on the distance to the sink node. The nodes have more remaining energy are chosen as Cluster Heads (CHs) in each layer [7]. The method of Energy Efficient Clustering with Sink as Cluster Head (EEC-SCH) puts forward to make the sink node as a CH to balance the energy consumption for whole network [8]. The Distance-Based LEACH (DB-LEACH) proposes to consider the distance factor to the threshold equation and the Distance-Based Energy-Aware (DBEA-LEACH) advances to consider the energy factor instead [9]. And the Cluster Based Routing Protocol for Mobile Nodes is proposed to save the energy for the mobility of the sensor nodes, which uses cross layer design between Medium Access Control (MAC) and network layers [10]. This kind of method performs better in WSNs with mobile sensor nodes. Simulation data show that the algorithms above improve network energy efficiency in varying degrees. But the applicability of these algorithms in the uneven energy distributed WSNs is discussed seldom.

In this paper, Dynamic K value LEACH (DK-LEACH) is proposed aims at the problems above. The K value is the proportion for the distance between the node to a CH and the residual energy of the CH. A threshold composed by the distance and energy factors has to be calculated when forming the clusters. The threshold equation is adjusted based on the distribution density of network nodes, which ensures to build a relatively stable cluster structure.

The organization of this paper is as follows. Section 2 discusses the DK-LEACH approach in details. This is followed by the simulation analysis in Sect. 3. Finally, Sect. 4 gives the conclusion of this paper.

2 The Proposed Method

2.1 Energy Consumption Model

The energy model is defined in the Atos-SensorSim simulation platform, which is a kind of simulator for wireless sensor networks [11]. The energy used to transmit ($E_t(m,d)$) and receive ($E_r(m)$) m bit of information in wireless communication is given by:

$$E_t(m,d) = (\alpha + \lambda * d^n) * m \tag{1}$$

$$E_r(m) = \beta * m \tag{2}$$

where α represents the consumed energy of communication transmission circuit, λ is the consumed energy of transmission amplifier, n is the path loss factor, d is the distance between the two nodes, β stands for the consumed energy of communication reception circuit.

2.2 DK-LEACH Protocol

Every sensor node in networks competes for CHs justly in LEACH, which ignores the residual energy of nodes and lead to the hole of energy consumption. So, for DK-LEACH, in the phase of selecting CHs, the nodes that have the higher residual energy than the average energy of the network have qualifications to compete for CHs. Then, the way to choose CHs is the same as LEACH [12]. The key improved part for DK-LEACH is that the function value D_c related to CH is calculated out and the minimum value is selected by nodes. The minimum value represents the selected CH has higher remaining energy and shorter distance to the node relatively. The function of D_c is defined as:

$$D_c(n) = k * \frac{d}{d_{max}} + (1 - k) * \frac{E_{init}}{E_{cur}}; \quad if\ n \in N \tag{3}$$

where k is the adjustable proportion parameter, $0 \leq k \leq 1$, d represents the distance between the node n to CH, d_{max} is the maximum distance between any two nodes, E_{init} is the initial energy of nodes, E_{cur} stands for the current remaining energy for node n, and N represents the congregation for non-CH nodes. The value for k is up to the nodes density D_{en} defined as:

$$D_{en} = \frac{N_r}{\pi * R^2} \tag{4}$$

where N_r is the number of nodes within communication radius of R. And the relational expression between k and D_{en} is defined as:

$$k = \begin{cases} 0.4 & if\ D_{en} \leq 0.002 \\ 0.8 & if\ D_{en} > 0.002 \end{cases} \tag{5}$$

Equation (5) is got by multi-simulations, the different network environments including different number of nodes and different scale of networks have been set, and the LEACH and DK-LEACH are simulated in the same networks. We changed the value of k from 0 to 1 by interval of 0.1, and then observed the changes of statistics. Finally, the relational expression between k and D_{en} is defined as Eq. (5). The partial simulation statistics of this process are displayed in Sect. 3 of this paper. DK-LEACH operates in two phases: setup phase for clusters; the other is steady state phase for data transmission.

- Setup phase for clusters.

Step 1 The BS calculates the average energy of network and broadcasts messages among network.

Step 2 The nodes that have the higher residual energy than the average value generate a random number between 0 and 1. If the random number is lower than the threshold, the node is chosen as the CH and then the CH broadcast messages. The threshold is defined as:

$$T(n) = \begin{cases} \dfrac{P}{1 - P * (r \bmod \frac{1}{P})}; & if\ n \in G \\ 0; & otherwise \end{cases} \tag{6}$$

where P represents the desired percentage of the number of CHs, r is the current round, G is the congregation for nodes that have not been CHs in the current rounds [13].

Step 3 When the non-CH nodes receive the messages from CHs, they calculate the nodes density D_{en} defined in Eq. (4). The k value is determined based on Eq. (5).

Step 4 The non-CH nodes calculate the function value $D_c(n)$ in Eq. (3), and select the minimum value of the corresponding CH to send messages for joining clusters.

Step 5 The CHs assign communication slots for every cluster members by TDMA mode.

- Steady state phase for data transmission.
  CHs gather and fuse the received data from cluster members, then send them to the BS. The stable phase keeps a period of time until the number of low-energy nodes attains 95% of the number of whole network nodes. The node that has remaining energy reaches 20% of its initial energy is called as the low-energy node, which has no qualification to compete for CHs. The setup phase for clusters will be rebuilt for cycling.

3 Simulation and Discussion

The comparative simulation of LEACH and DK-LEACH is carried out in Atos-SensorSim platform. A clustered WSN in a field with dimension as 100 m * 100 m is simulated. The total number of nodes is 400. The BS is located at the centre of this field. The default values of simulation parameters are listed in Table 1. Firstly, the simulations for Eq. (5) is carried out. Secondly, the simulation is complied for the network of the even nodes distribution and the uneven nodes distribution respectively.

3.1 Simulations for the Source of Eq. (5)

We set the number of nodes from 100 to 800 by interval of 50 in the same even distributed networks, and set the value of k from 0 to 1 by interval of 0.1 when change the number of nodes. The lifetime evaluation for LEACH and DK-LEACH with different value of k in the 100 m * 100 m network is simulated. The ratio of living nodes is calculated when the number of rounds is 200 and 400 for these two algorithms. The simulation results are counted and the partial statistical curves are shown in Figs. 1, 2 and 3.

Figures 1 and 2 shows that the ratio of living nodes for DK-LEACH is higher than LEACH when the number of nodes is 100 with any value of k. And the ratio is highest when the value of k is 0.4. In Figs. 3 and 4, when the network nodes are densely distributed

Table 1 Default values of simulation parameters

Parameter	Value
Number of nodes	400
Initial energy	20 J
Radio range	70 m
Data packet size	192 bits
d_{max}	120 m
P	0.05
α	45 nJ/bit
β	135 nJ/bit
λ	10 pJ/bit/m^2

relatively, the ratio of living nodes get the highest value with the k value of 0.8. So, after these multi-simulations analyses, we get the relational expression between k and D_{en} as Eq. (5).

3.2 Network of Even Nodes Distribution

The density of nodes distribution is stable relatively for this kind of situation. And its average value is 0.025 based on Eq. (4), the value of k is chosen as 0.8 in Eq. (5). The network of nodes distribution is shown in Fig. 5.

The relationship of the number of living nodes with time (number of rounds) for the two algorithms is verified. And the connection between the total consumed energy and time (number of rounds) is simulated. The results are shown in Figs. 6 and 7.

The survival rate of nodes in DK-LEACH is higher than 56.25% compared to the 47.5% of LEACH before rounds of 300, which is shown in Fig. 6. DK-LEACH has less consumed energy than LEACH, which is shown in Fig. 7. Compared to LEACH, the proposed protocol reduces 200 J of total consumed energy evenly, which means the reduction in consumed energy is around 0.05 J for every nodes. Thus, in the even energy distribution case of WSNs, DK-LEACH improves survival rate of nodes and reduces energy consumption effectively, prolongs the lifetime of network thereby.

3.3 Network of Uneven Nodes Distribution

For the uneven nodes distributed network, k value is dynamically adjusted for DK-LEACH. The network of nodes distribution is shown in Fig. 8.

Similarly, the simulation results of the number of living nodes with time for the two algorithms are shown in Fig. 9. And the simulation results of the consumed energy with time are shown in Fig. 10.

The survival rate of nodes in DK-LEACH is higher than 42.5% compared to the 31.25% of LEACH before rounds of 200, which is shown in Fig. 9. The rate of nodes is improved 11.25% than the traditional clustering routing protocols LEACH. However, compared to Fig. 7 simultaneously, the rate of survival nodes decreased evidently for the two methods.

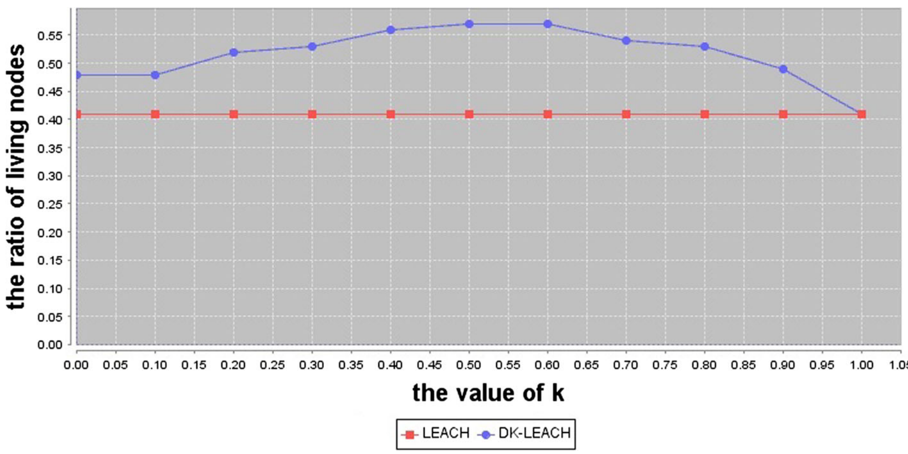

Fig. 1 The lifetime evaluation for 100 nodes distributed with 200 rounds

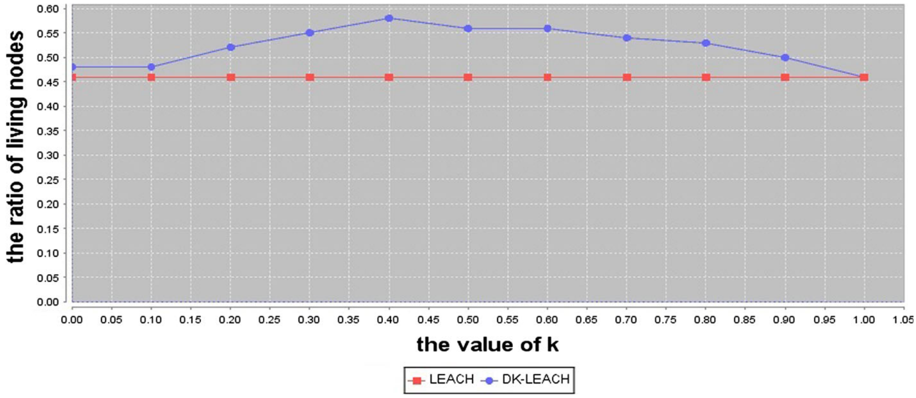

Fig. 2 The lifetime evaluation for 200 nodes distributed with 200 rounds

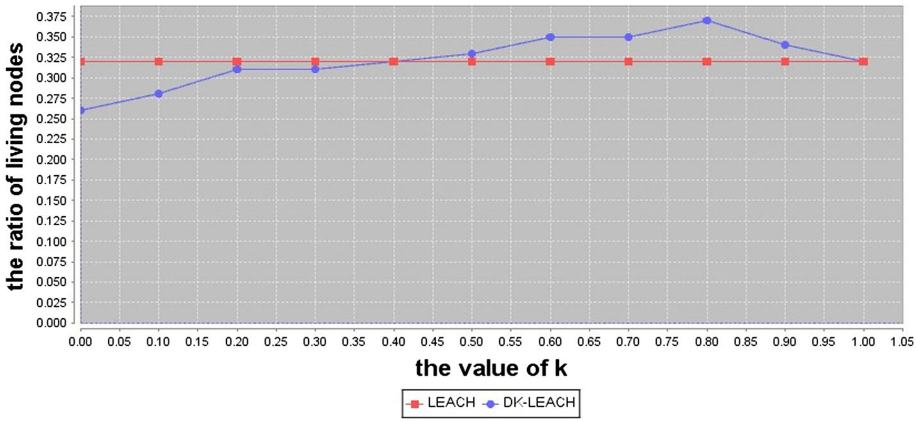

Fig. 3 The lifetime evaluation for 400 nodes distributed with 400 rounds

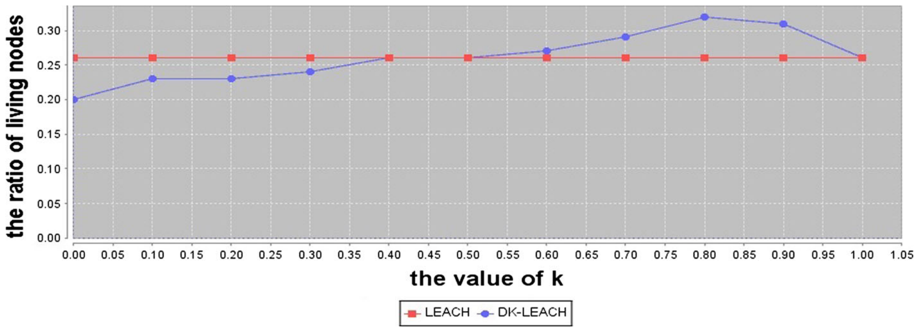

Fig. 4 The lifetime evaluation for 800 nodes distributed with 400 rounds

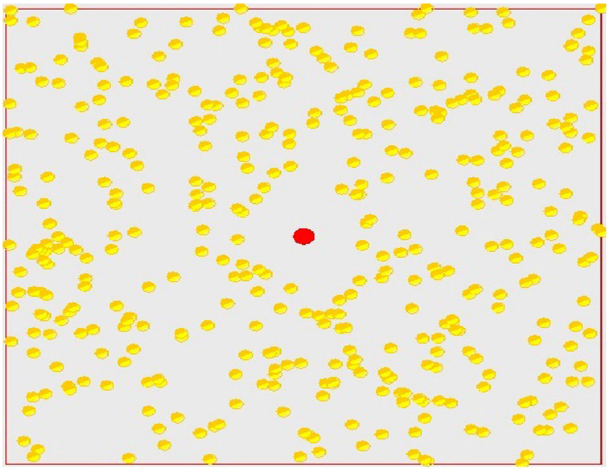

Fig. 5 Network with even nodes distribution

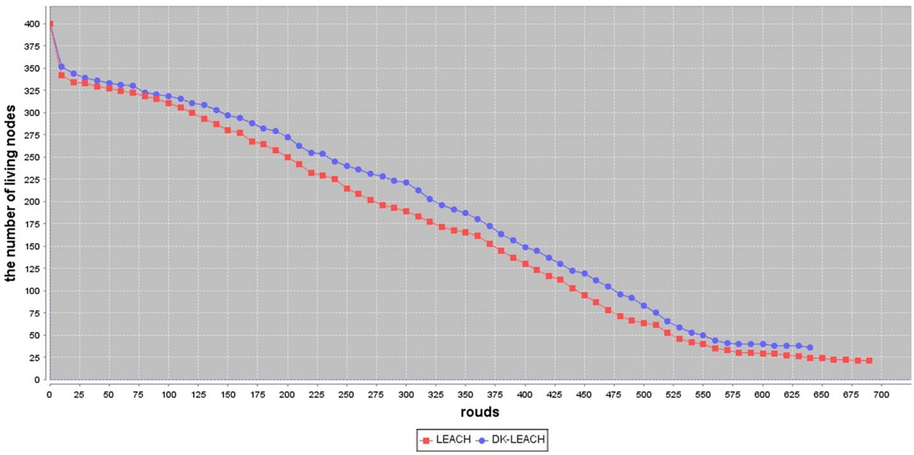

Fig. 6 The lifetime evaluation of protocols for even network

So it is proved that the LEACH has better performance in the network with even nodes distribution. Also, DK-LEACH has less consumed energy than LEACH, which is shown in Fig. 10. Compared to LEACH, the proposed protocol reduces 160 J of total consumed energy evenly. Thus, in the uneven energy distribution case of WSNs, DK-LEACH performs better than LEACH, which improves survival rate of nodes and decreases energy consumption effectively.

4 Conclusion

In wireless sensor networks, LEACH performs better than the planar multi-hop routing protocols in energy efficiency. But it is not well-adapted in the network with uneven energy distribution. In this paper, DK-LEACH is proposed to optimize the cluster structure

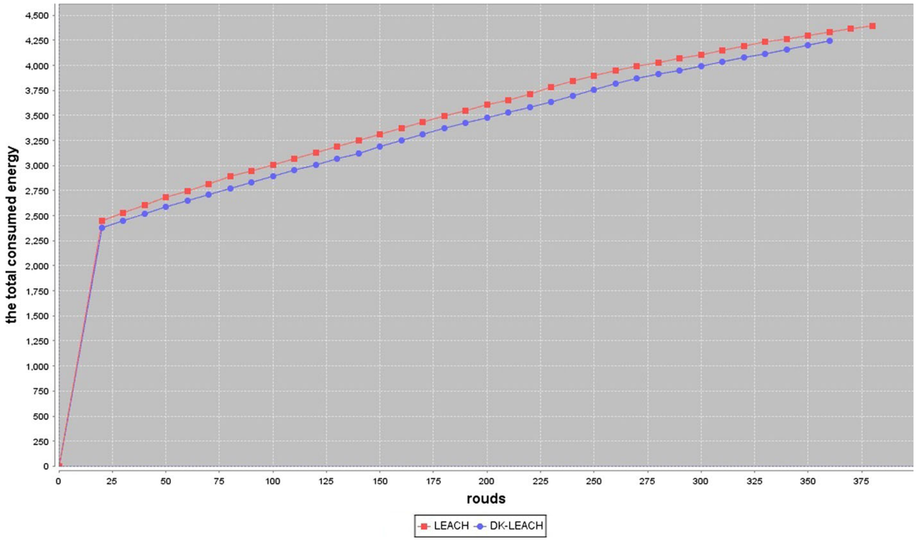

Fig. 7 The total consumed energy of protocols for even network

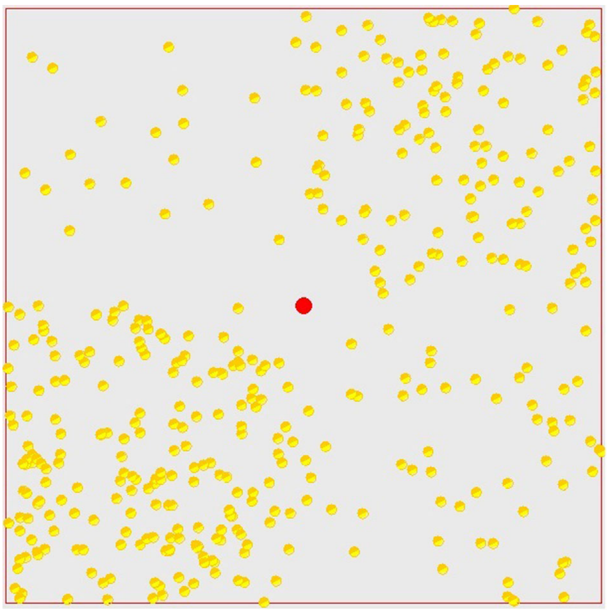

Fig. 8 Network with uneven nodes distribution

based on these problems. Compared with LEACH, during the phase of clusters setup, the nodes consider the distance factor and the surplus energy of CHs synthetically. From this, the consumed energy for CHs can be balanced effectively. The simulation results show that the DK-LEACH can improve the rate of survival nodes by 11%, which prolongs the

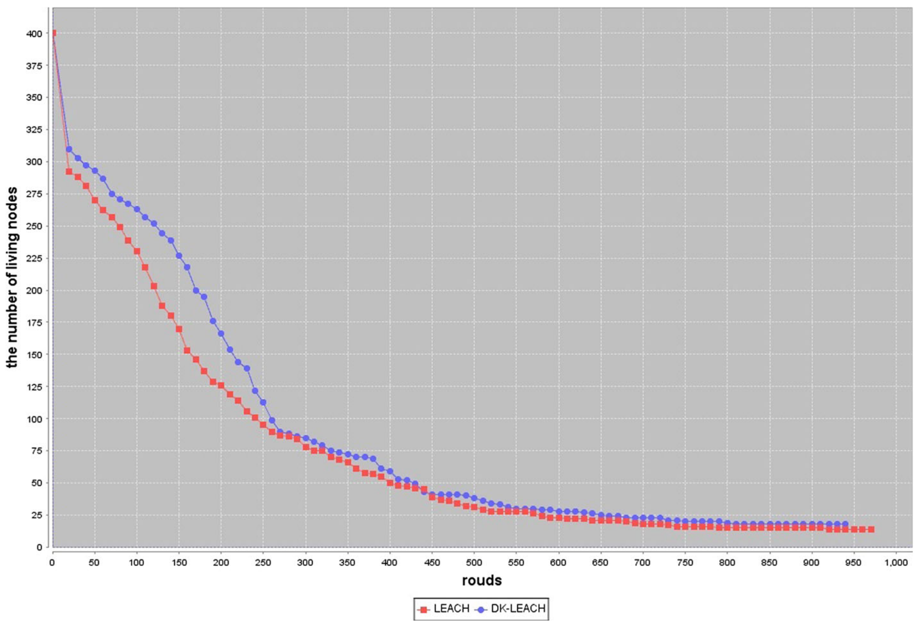

Fig. 9 The lifetime evaluation of protocols for uneven network

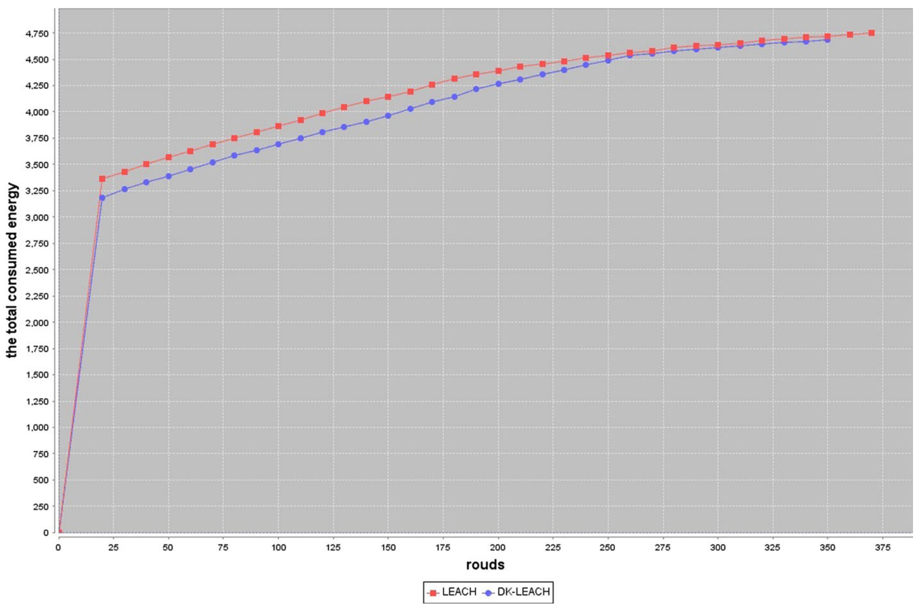

Fig. 10 The total consumed energy of protocols for even network

network lifetime. This kind of algorithm idea adjusts to the large sensor acquisition scene with centralized distribution of sensors, such as warehouse management, agricultural greenhouse management, and so on.

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References

1. Zahariah, M., Borhanuddin, M. A., Chee, K. N., Nor, K. N., & Aduwati, S. (2013). A review on hierarchical routing protocols or wireless sensor networks. *Wireless Personal Communications*. doi:10.1007/s11277-013-1056-5.
2. Jokhio, S. H., Jokhio, I. A., & Kemp, A. H. (2013). Light-weight framework for security-sensitive wireless sensor networks applications. *IET Wireless Sensor Systems*, *3*(4), 292–306.
3. Byun, J., Jeon, B., Noh, J., Kim, Y., & Park, S. (2012). An intelligent self-adjusting sensor for smart home services based on ZigBee communications. *IEEE Transactions on Consumer Electronics*, *58*(3), 794–802.
4. Shin, J., & Suh, C. (2011). CREEC: Chain routing with even energy consumption. *IEEE Communications and Networks Journal*, *13*(1), 17–25.
5. Xie, W. X., Zhang, Q. Y., Sun, Z. M., & Zhang, F. (2015). A clustering routing protocol for WSN based on type-2 fuzzy logic and ant colony optimization. *Wireless Personal Communications*. doi:10.1007/s11277-015-2682-x.
6. Munir, A. (2015). Cluster based routing protocols: A comparative study. In *IEEE fifth international conference on advanced computing and communication technologies (ACCT)* (pp. 590–594). Haryana.
7. Gautam, N., & Pyun, J. Y. (2010). Distance aware intelligent clustering protocol for wireless sensor networks. *IEEE Communications and Networks Journal*, *12*(2), 122–129.
8. Jain, A., & Reddy, B. V. R. (2014). Sink as cluster head: An energy efficient clustering method for wireless sensor networks. *IEEE international conference on data mining and intelligent computing (ICDMIC)* (pp. 1–6). New Delhi.
9. Nguyen, T. G., So-In, C., & Nguyen, N. G. (2014). Two energy-efficient cluster head selection techniques based on distance for wireless sensor networks. In *IEEE international conference on computer science and engineering conference (ICSEC)* (pp. 33–38). Khon Kaen.
10. Awwad, S. A. B., Ng, C. K., Noordin, N. K., & Rasid, M. F. A. (2010). Cluster based routing protocol for mobile nodes in wireless sensor network. *Wireless Personal Communications*. doi:10.1007/s11277-010-0022-8.
11. Rappaport, T. S. (1996). *Wireless communications: Principles and practice*. New York: Prentice-Hall.
12. Barati, H., Movaghar, A., & Rahmani, A. M. (2015). EACHP: Energy aware clustering hierarchy protocol for large scale wireless sensor networks. *Wireless Personal Communications*. doi:10.1007/s11277-015-2807-2.
13. Heinzelman, W. R., Chandrakasan, A., & Balakrishnan, H. (2000). Energy-efficient communication protocol for wireless microsensor networks. In *Proceedings of the 33rd annual Hawaii international conference on system sciences*. Hawaii.

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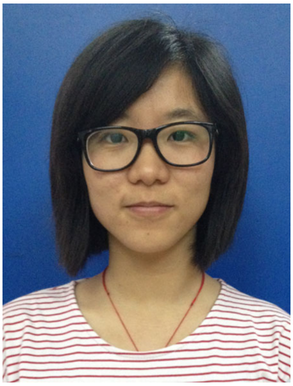

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