Journal of Computers Vol. 29 No. 3, 2018, pp. 188-196
doi:10.3966/199115992018062903017

A Novel Comprehensive Optimization Routing Algorithm Based on Ladder Diffusion

Yan-Hong Hu[1,2], Yu-Hai Li[1*], Wen-Qi Xie[3]

[1] Department of Information Management, Central China Normal University, Wuhan, China
{hugo, yhli}@mail.ccnu.edu.cn

[2] College of Vocational and Continuing Education, Central China Normal University, Wuhan, China
hugo@mail.ccnu.edu.cn

[3] School of Computer Science, Yangtze University, Jingzhou, China
xieviki650@gmail.com

Received 13 September 2017; Revised 13 October 2017; Accepted 9 November 2017

Abstract. It is known to all that Wireless Sensor Networks (WSN) is plagued by the energy shortage caused by the environment factors. In this paper, a novel energy-saving algorithm named COLD is proposed. Which is based on ladder diffusion and comprehensive optimization. In COLD, firstly, ladder diffusion is introduced to decide the sink nodes number. Then, the best nodes will be selected under comprehensive optimization strategy, which residual energy of the node, communication costs and average energy are considered together. Finally, In the routing selection phase, both distance and the difference of the angle will be taken into consideration. A non-uniform clustering was used to deal with "hot area" problem. Experimental results show that the proposed COLD has better performance than other related routing algorithms in several aspects, such as life cycle, the average residual energy of whole nodes, and energy consumption balance.

Keywords: comprehension optimization, energy consumption balance, energy saving algorithm, ladder diffusion, no-uniform clustering

1 Introduction

In general, wireless sensor network (WSN) is unable to replenish energy of each nodes by the limitation of low battery. Once a senor node's energy is exhausted, wireless sensor network leaks will appear, and failure nodes will not relay data to the other nodes during transmission processing [1]. It is necessary for WSN algorithm to save nodes energy and prolong the life cycle. Some Scholars have proposed many related energy-saving routing algorithms [2-10].

Heinzelman W et al. firstly proposed clustering algorithm LEACH [3] in 2000. Their idea about clustering is widely used in WSN, but energy consumption is too large to balance the life cycle of the whole WSN. Wan C, et al. in 2003 proposed CODA [6] which presented a non-uniform clustering algorithm to balance energy consumption between sink nodes. It performed good to save the energy of outer sensor node. Liu and Ji Zheng ding proposed RMBC [10] evolved from CODA to build a multi-hops algorithm in 2008, and it has prettier performance than CODA in energy balance. These related energy-saved routing algorithms are proposed based on a single object, they achieve good performance on a specified object, such energy consumption, residual energy, life cycle and so on. Generally, the WSN is considered as a whole unity, the routing algorithm was designed under one object will cause that some key nodes were used too frequently, the life cycle of the WSN will be shortened. It is very important to designed some new routing algorithms based on multi-object to solve the balance of energy

* Corresponding Author

consumption, residual energy, life cycle and so on.

In this paper, a comprehensive optimization routing algorithm Based on ladder diffusion (COLD) is proposed to solve energy and communication costs problems. And COLD comprises three steps:

(1) Ladder diffusion phase will divide the entire wireless network into several layers to build multi-hops transmission model that can effectively optimize the average residual energy of the entire network.

(2) Sink node election phase. The optimal sink node number formula is adopted to calculate each gradient's sink nodes. In order to balance the energy consumption, the density of sink node near the base station is larger, and the clustering size is smaller.

(3) Routing formation phase. 'Hot area' problem will be settle by using the minimum energy consumption model.

The paper is organized as follow: Section 2 explains the technical details of ladder diffusion algorithms, Section 3 proposes the COLD algorithm. Section 4 shows experimental results and analyze features. Section 5 summarizes the COLD algorithm and new trends will be discussed.

2 Related Work

We would like to stress that the class/style files and the template should not be manipulated and that the guidelines regarding font sizes and format should be adhered to. This is to ensure that the end product is as homogeneous as possible. In this section, the ladder diffusion routing algorithm algorithms are discussed.

As described in [6, 10], the ladder diffusion algorithm is an effective way to control energy consumption of sensor nodes.

Ho et al proposed LD algorithm [1] in 2012. It employs two mechanisms in ladder diffusion phase: receive package and broadcast package. First of all, sensor nodes compare its own ladder with the ladder value recorded in the received package. And then if the value of the package is smaller, sensor nodes updates the original one to the recorded one. If not, sensor nodes discard the package.

For example, in the Fig. 1, the first package is broadcast by base station A conclude a ladder value of 1 which means the sensor nodes can transmit packages by one hop. Nodes B and C records their ladder value as 1 and previous sink node as after receiving the broadcast from A. Then, they broadcast package with a ladder value of 2 which means the sensor nodes needs two hops to transmit package to base station. After nodes f, e, d, and b receives a ladder package with a ladder value of 2 respectively, f, e, and d will record their ladder value as 2 and previous sink node as B or C, and then broadcast a package with ladder value of 3. Meanwhile, node B discards the broadcast recorded larger ladder value.

In the network working phase of LD, the nodes with a large number of ladder transmit the data to the previous sink node through their records. Using the concept of ladder diffusion, the energy consumption of the sink nodes away from the base station node is equalized to other nodes.

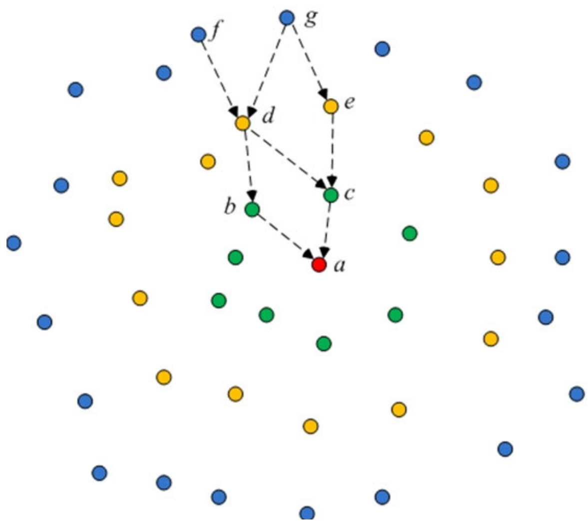

Fig. 1. The ladder diffusion diagram

In CODA [6], the idea of selecting different clustering head nodes in different regions based on ladder distance is introduced to solve the problem of high energy consumption nodes far away from the base station. Since more sink nodes are selected in the remote areas in CODA, the clustering scale and energy consumption are smaller in remote areas. Nevertheless, as the size of the network increases, the energy consumption will also increase and the life cycle will be shortened.

RBMC algorithm [10] proposes a multi-hops algorithm based on CODA algorithm to solve the problem of large-scale energy consumption through distributing the increased energy consumption to other sink nodes. Although RBMC makes the energy consumption balanced, the sink node near the base station transmits more energy and generates the problem of “hot area”.

3 The Proposed Comprehensive Optimization Algorithm Based on Ladder Diffusion

In this section, the detail processes of COLD that based on ladder diffusion to solve the energy and communication cost problems are presented.

3.1 Ladder Diffusion Phase

In this paper, ladder diffusion algorithm is used to avoid high waste in communicate between sensor nod. The process of ladder diffusion phase is as follows.

First, wireless sensor network will be regarded as a circular area centered on base station. As show in the Fig. 2, the radius of the whole area is 180m which is divided into three concentric rings based on the width of 60m.The three areas are called the first ladder, the second ladder and the third ladder respectively from the center to the boundary.

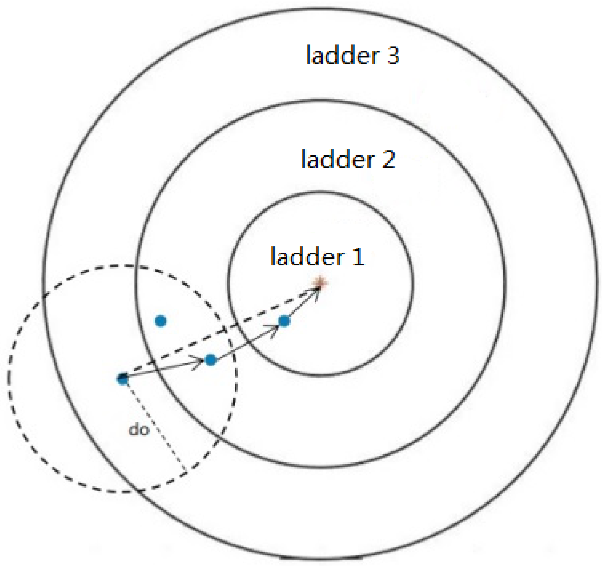

Fig. 2. The circular area based on ladder

After being divided into concentric rings, wireless sensor network will determine the optimal number of sink node and elect sink node for each clustering.

The optimal sink nodes are calculated form the optimal sink nodes formulation. In WSN, the sensor nodes near base station takes more transmit mission as they transmit many other packages. In order to balance the energy consumption and prolong the whole life cycle of the whole WSN, the calculate formula (1) and (2) are used [11].

$$CH_{layer}(L) = \sqrt{\frac{N(L)}{2}} \frac{d_{la}}{\sqrt{E[d_{ch}^2(L)]}} \quad \textbf{(1)}$$

Where CHlayer (1) is the optimal sink nodes of first ladder, N (1) is the number of sensor nodes in the first ladder, d_{la} is the width of the concentric, $E[d_{ch}^2(L)]$ is expected value of the square of the distance between sink nodes to base station in first ladder.

The total energy consumption of each k-ladder [22-23] is:

$$E_{ch} = \frac{N(K)(E_{elec} + \mathrm{E}_{da}) + \sum_{i=K+1}^{S} mi(2E_{elec} + \mathrm{E}_{fs}\mathrm{E}[\mathrm{d}_{ch}^2(\mathrm{K})\text{-}\mathrm{d}_{ch}^2(\mathrm{K\text{-}L})]) + m_k E_{fs} E[\mathrm{d}_{ch}^2(K) - \mathrm{d}_{ch}^2(K-L)]}{CH_{layer}(K)}. \quad \textbf{(2)}$$

Then let $E_{ch}(K) = E_{ch}(L)$, optimal sink nodes of each ladder will be calculated out. By controlling the number of sink node in each ladder, the number and the size of each clustering can also be controlled. The internal and external nodes can mutually compensate other nodes energy consumption by using this calculation method which can adjust density of every clustering.

Finally, the specific location of each clustering will be determined. Each ladder is equally divided into CHlayer(k) sectors. The angle size of each sector is $2\pi / CH_{\text{layer}}(\mathrm{K})$.

Ladder and clustering number of each nodes will be distributed by their location. Then the whole WSN is divided into many different clustering.

3.2 Sink Node Selection Phase

COLD algorithm has two parts in sink node selection phase. The first step is to select the candidate sink nodes of clustering and the second step is to determine the final sink node. Both of energy consumption and life cycle are been considered in the two parts.

The first step uses a threshold calculation formula similar to the LEACH [3, 12-13]. The COLD introduces residual energy into the threshold calculation formula to form a new formula (3). According to the formula, firstly every node will generate a random number between 0 to 1 and then calculates their own T(n) value. Candidate sink nodes will be those nodes whose T(n) is less than the threshold [14-16].

$$T(n) = \begin{cases} \dfrac{p_k}{1 - p_k[r \bmod (1/p_k)]} \times \dfrac{E_{current}}{E_{avg}} & \mathrm{n} \in G \\ 0 & \mathrm{n} \notin \mathrm{G} \end{cases}. \quad \textbf{(3)}$$

In formula (3), p_k is the ratio of sink node to ladder k; r indicates the current cycle; G represents the set of nodes which was not elected in the most recent $1/p_k$ round; $E_{current}$ represent the residual energy of the node; E_{avg} is the average energy of overall network. The sensor nodes with large remaining energy is more likely to become candidate sink node by using formula (3).

After Candidate sink nodes are decided, second step will use communication cost model similar to HEED [17-19] to choose final sink node. In HEED, the cost model is performed without taking clustering into account, resulting too much iteration and complexity. On the contrast, COLD algorithm has low time complexity for calculating communicate cost in clustering.

In COLD, internal communication cost model consist of four procedures. First, every candidate sink nodes calculates their internal communication cost (the square of the distance between the candidate to other candidates). Then each candidate checks if its communication cost is the lowest through receiving package from other candidates. Once a candidate sink node convince its cost is the lowest in its clustering, it will broadcast a package conclude locations, ID, ladder number and clustering number to other node in its clustering. Finally, the other node will be assign a TDMA schedule telling them when to transmit according to their sequence of broadcast confirming message to final sink node.

3.3 Routing Formation Phase

In order to solve the problem of 'hot zone' of algorithm and reach the objects of balance the energy consumption and prolong life cycle, COLD uses advanced multi-hops algorithm during the formation of routing phase.

In the first part, all sink nodes broadcast their ID and locations to other sink nodes. If sink node received a broadcast from lower ladder and their distance is less than do, it will memory the lower ladder sink node as next hop. In the second part, each sink node will choose its next hop which is nearest the connection between base station. These steps will solve the problem of highly energy consumption caused by using signal amplify circuit and effectively reduce the communication costs between clustering.

4 Experimental Results and Analysis

LEACH, RBMC, COLD is implemented in this section to compare their performance in the same environment. The main parameters include life cycle, remaining sink nodes, residual energy of per round and energy balance ability.

We simulate LEACH, RBMC and COLD using MATLAB with 400 random sensor nodes in a circuit which radius is 180m shown in Fig. 3. The area is divided into three concentric rings based on the same width 60m.And each layer will be divided into several clustering bases on the optimal sink node numbers calculated from formula (1) and (2).

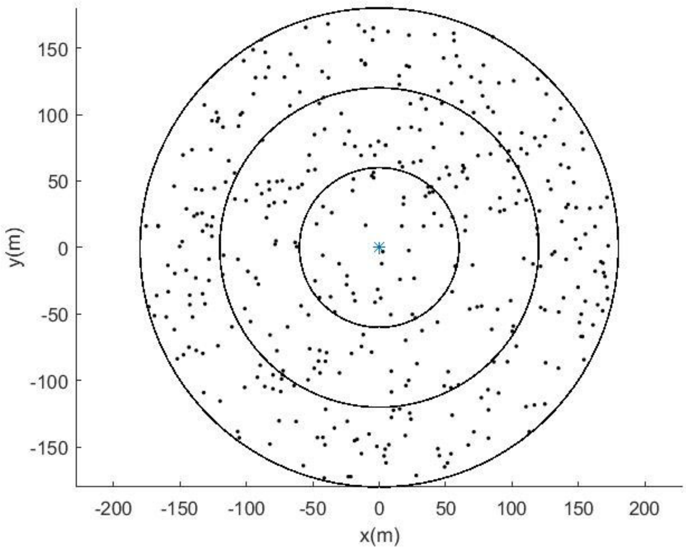

Fig. 3. Initial distribution of WSN

4.1 Comparison with Related Routing Algorithms Based on Life Cycle

Table 1 represents the death parameters in LEACH, RBMC and COLD. We can see from the table that COLD is much better than LEACH and RBMC. COLD delay 690 and 421 rounds respectively to LEACH and RMBC until the first dead node emerged. The life cycle is prolonged 350% compared to LEACH and 15% to RMBC. Applied with multi-hops algorithm and non-uniform clustering algorithm is the main reason COLD perform better.

Table 1. Death paraments

stander	LEACH	RBMC	COLD
First dead	361	630	1051
10% dead	375	1101	1420
All dead	438	1703	1975

4.2 Comparison with Related Routing Algorithms Based on Remaining Nodes and Residual Energy of Per round

Fig. 4 and Fig. 5 shows that COLD can effectively reduce the energy consumption of each sink node compared to COLD and LEACH. COLD didn’t have any dead node when nodes started to bead in LEACH and RMBC.

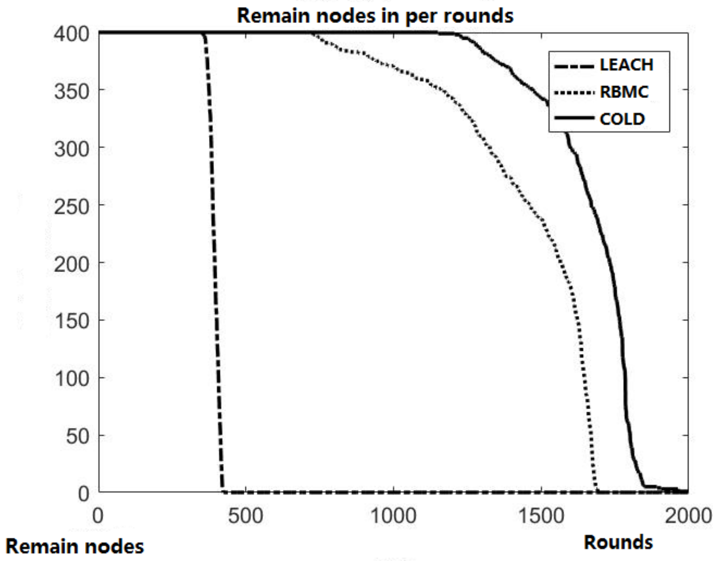

Fig. 4. Remain nodes in per rounds

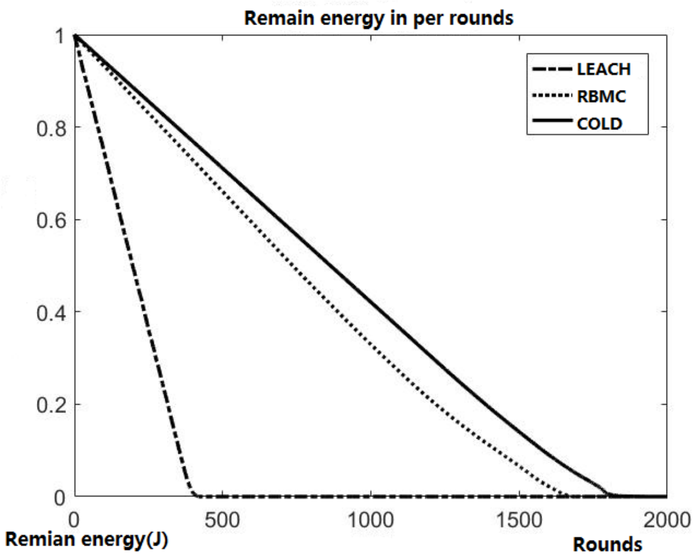

Fig. 5. Comparison based on the remain energy among related algorithms

4.2 Balance of the Energy Consumption

Fig. 6 gives the initial state of the WSN. Fig. 7 to Fig. 9 gives the energy distribution of LEACH, RMBC and COLD. It can be concluded that COLD can balance the energy consumption between the inner and outer nodes in a large extend. According to Fig. 8, outer nodes dead a lot when half nodes remains. On the contrast, RMBC lost almost all of its inner nodes after half nodes remains. However, at the same time, COLD has pretty good performance in balancing the energy consumption of WSN

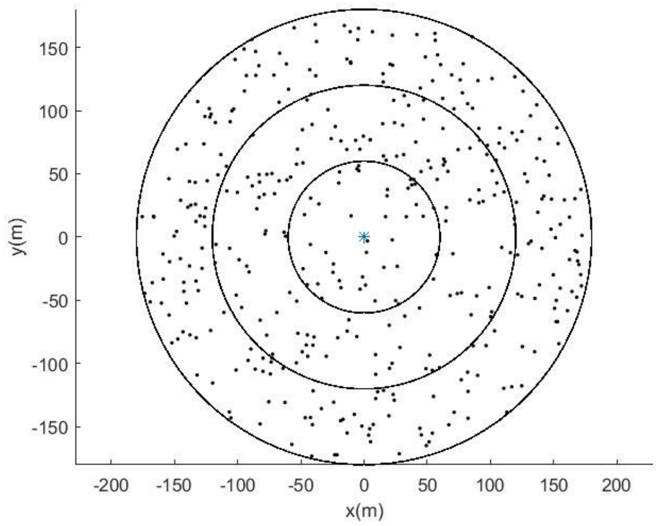

Fig. 6. The distribution of initial nodes

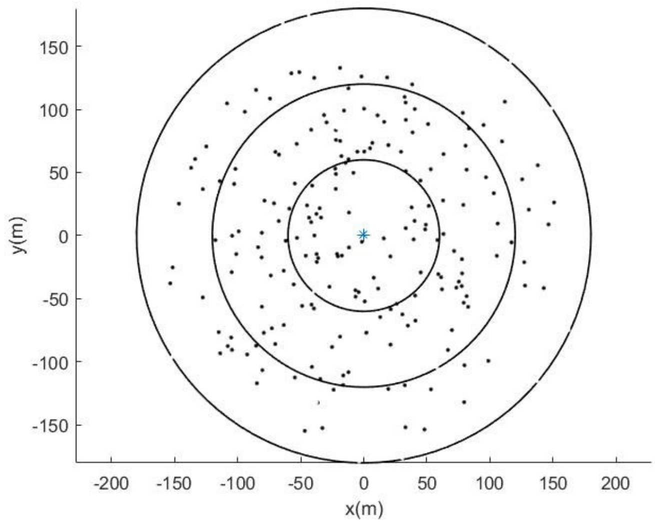

Fig. 7. LEACH half nodes dead

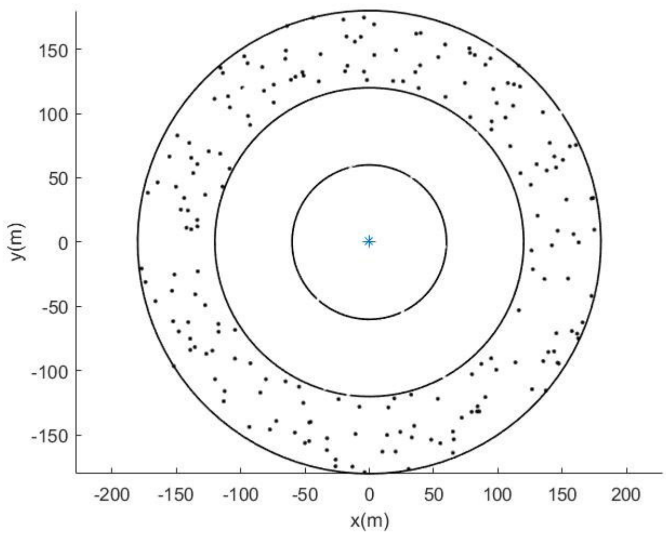

Fig. 8. RMBC half nodes dead

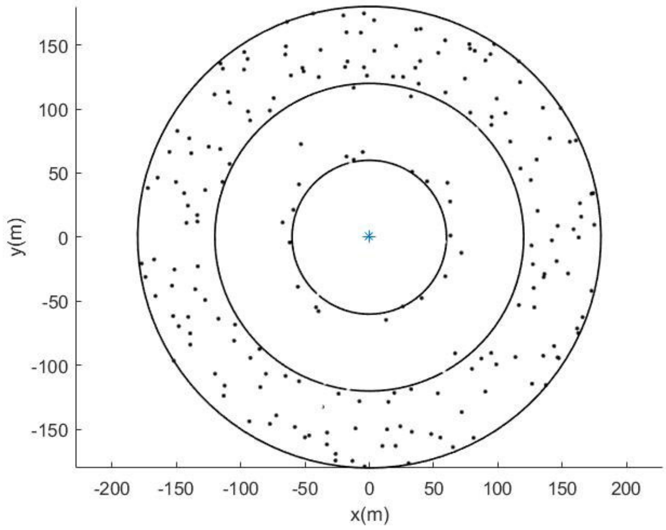

Fig. 9. COLD half nodes dead

5 Conclusion

In this paper, we presented an algorithm COLD based on ladder diffusion and comprehensive optimization to solve the problem of power consumption and life cycle in wireless sensor network.
In conclusion, we make some improvements in COLD:

First, ladder diffusion is employed to division the WSN and form the routing to solve the "hot areas" problem and reduce the energy of forming a route table. Moreover, to ensure comprehensive optimization, residual energy, communication costs and average energy all be considered. Taking residual and average energy into account ensure that low energy nodes will be eliminate at the sink node election phase. At the same time, communication cost estimation has an excellent performance in balancing the consumption between inner and outer sink nodes.

According to the experimental results, though compared to other algorithms, COLD still has better performance. This novel ladder diffusion algorithm may pave a new path in clustering algorithm.

References

[1] J.H. Ho, H.C. Shih, B.Y. Liao, A ladder diffusion algorithm using ant colony optimization for wireless sensor networks, Information Sciences 192(2012) 204-212.

[2] M.J. Handy, M. Haase, D. Timmermann, Low energy adaptive clustering hierarchy with deterministic cluster-head selection, in: Proc. the 4th International Workshop on Mobile and Wireless Communications Network, 2002.

[3] W. Heinzelman, A. Chandrakasan, H. Balakrishnan, Energy-efficient communication protocols for wireless Microsensor networks, in: Proc. the 33rd Annual Hawaii International Conference on Systems Science (HICSS), 2002.

[4] J. Yick, B. Mukherjee, D. Ghosal, Wireless sensor network survey, Computer Networks 52(12)(2008) 2292-2330.

[5] W.B. Heinzelman, A.P. Chandrakasan, H. Balakrishnan, An application-specific protocol architecture for wireless microsensor networks, IEEE Transactions on Wireless Communications 1(4)(2002) 660-670.

[6] C. Wan, S. Eiseman, A. Cambell, CODA: congestion detection and avoidance in sensor networks, in: Proc. the 1st ACM Conference on Embedded Networked Sensor System, 2003.

[7] H.O. Tan, I. Körpeoglu, Power efficient data gathering and aggregation in wireless sensor networks, ACM Sigmod Record 32(4)(2003) 66-71.

[8] B, Manzoor, N. Javaid, O. Rehman, Q-LEACH: a new routing protocol for WSNs, Procedia Computer Science 19(2013)

926-931.

[9] L. Kong, C. Chen, C.M. An energy-aware routing protocol using cat swarm optimization for wireless sensor networks, in: Y.-M. Huang, H.-C. Chao, D.-J. Deng, J.J. Park (Eds.), Advanced Technologies, Embedded and Multimedia for Human-centric Computing, Springer Netherlands, New York, 2014, pp. 311-318.

[10] Z.Q. Liu, D. Zheng, Ring based multi-hop clustering routing algorithm for wireless sensor networks, Journal on Communication 29(3)(2008)104-113.

[11] Z.J. Haas, J.Y. Halpern, L. Li., Gossip-based ad hoc routing, IEEE/ACM Transactions on networking 14(3)(2006) 479-491.

[12] S. Tyagi, N. Kumar, A systematic review on clustering and routing techniques based upon LEACH protocol for wireless sensor networks, Journal of Network and Computer Applications 36(2)(2013) 623-645.

[13] S.H. Lee, J. Yoo, T.C. Chung, Distance-based energy efficient clustering for wireless sensor networks, in: Proc. IEEE international Conference on Local Computer Networks, 2004.

[14] W.R. Heinzelman, A. Chandrakasan, H. Balakrishnan, Energy-efficient communication protocol for wireless microsensor networks, in: Proc. the 33rd Annual Hawaii International Conference on System Sciences, 2000.

[15] F.J. Shang, M. Abolhasan, T. Wysocki, Distributed energy efficient unequal clustering algorithm for wireless sensor networks, Journal on Communications 30(10)(2009) 34-43.

[16] W.R. Heinzelman, A.P. Chandrakasan, H. Balakrishnan, An application-specific protocol architecture for wireless microsensor network, IEEE Transactions on Wireless Communications 1(4)(2002) 660-670.

[17] M. Younis, M. Youssef & K. Arisha, Energy-aware routing in cluster-based sensor networks, Analysis and Simulation of Computer and Telecommunications Systems, (2002) 129-136.

[18] J. Galletly, Evolutionary Algorithms in Theory and Practice Evolution Strategies, Evolutionary Programming, Genetic Algorithms, Oxford University Press, London, 1996.

[19] J. Kennedy, Particle swarm optimization. <https://link.springer.com/referenceworkentry/10.1007%2F978-0-387-30164-8_630>, 2011.