Sensors & Transducers, Vol. 171, Issue 5, May 2014, pp. 1-6

Sensors & Transducers

http://www.sensorsportal.com

A Low Energy Algorithm of Wireless Sensor Networks Based on Fractal Dimension

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Received: 23 April 2014 /Accepted: 23 May 2014 /Published: 31 May 2014

Abstract: For the energy limitation of nodes and imbalance energy consuming among nodes, this paper proposes an optimization algorithm --Low Energy Algorithm-- of wireless sensor networks based on fractal dimension algorithm for the purpose of reduction of the energy consumption. The nodes in WSN cannot be located evenly, and cannot move with the monitoring environment changed once be located. Considering the characteristics of WSN, the paper designs an optimized clustering method accompany with dimension by calculating the dimension of each cluster to determine the cluster which needs to be adjusted dynamically. If the cluster with high value of dimension, increasing more nodes in this cluster. If the cluster with low value of dimension, reducing more nodes in the cluster. The simulation results show that the LEA algorithm improves energy efficiency, prolongs the network lifetime, and balances energy consumption in the sensor network.

Keywords: Wireless sensor networks, Fractal dimension, Box covering algorithm, Low energy.

1. Introduction

In recent years, with the rapid development of communication and sensor technologies, Wireless Sensor Networks (WSN) are emerging in many industrial and consumer area. After a large number of sensor nodes are distributed randomly in the monitoring area, they have the capability of self organization among all nodes to construct a WSN [1]. The nodes in the network work collaboratively to processing information. WSN is characterized as self-organization and simple to deploy [2]. WSN is distributed throughout industry, agriculture, military and transportation. In recent studies of complexity network, people found that WSN has the same structural features of a tree-like hierarchical cluster, it can be seen as a complex network implementation, and can be studied by using fractal theory [3].

WSN has had some clustering algorithms, such as LEACH, PEGASIS and BCDCP. LEACH as the basis of many clustering algorithms is the classic algorithm and widely used. Classic clustering algorithms take more consideration in node energy and base station energy consumption, meanwhile the monitoring environment of WSN cannot be predicted and assessed accurately.

The ideal conditions for WSN are nodes evenly distributed in the open area, and the data quantity of measurement is steady in each area. However in practical, the nodes are randomly distributed and the monitoring data in each area has a great differences. For example, to monitor one lake water quality, the

monitoring data of the nodes in pollution area is greater than none pollution area. The data is richer in aspect of variation and difference which means more complicated. Therefore, the unevenly distributed network and the dynamic environments will affect the monitoring efficiency of WSN and reduce network's lifetime. To increase the efficiency of WSN and extend the lifetime, the sensor network need to be optimized by reducing the complexity of the network. How to improve the monitoring efficiency by using the clustering algorithms is need to be studied.

2. Clustering Protocol

2.1. LEACH Overview

Low Energy Adaptive Clustering Hierarchy (LEACH) [4] is a classical algorithm. This paper proposes an optimization method based on LEACH algorithm. The principle of LEACH is randomly selecting the nodes as clusters head cyclically. The cluster head sends the integrated data which received from each node to the base station.

The randomized rotation of cluster head in each cluster can save the energy consumption of nodes, balance network load, and reduce the network energy consumption [5, 6]. The typical WSN LEACH algorithm clustering structure shown in Fig. 1.

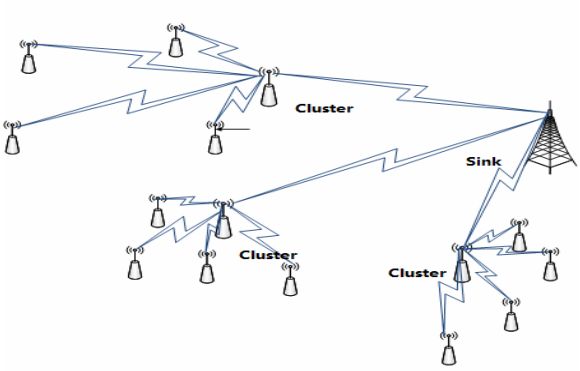

Fig. 1. WSN LEACH cluster structure.

The LEACH protocol defines two concepts: the "round" and the "cycle". The operation in one round can be categorized into two phases: named the initialization phase and the steady phase [7, 8].

2.2. Problems and Discussion

LEACH protocol is able to provide a simple networking approach of WSN, but it does not take more consideration for the node unevenly deployed situation due to the complexity monitoring environment, it also cannot make any adjustment for it.

The optimization is based on improvement of LEACH protocol. It proposes an idea to change the number of online node in monitoring area by judging the complexity of cluster in order to optimize the deployed self-organized network. Reducing the number of nodes for cluster of lower level complexity can reduce energy consumption and extend the network lifetime. Adding the number of nodes for cluster of higher complexity level can improve the monitoring efficiency of cluster and optimize cluster structure. Calculating the fractal dimension of network is used to obtain the complexity value. According to the fractal theory, the fractal dimension of network usually means network complexity value. The optimization based on LEACH protocol is proposed in this paper.

3. Method to Calculate the Fractal Dimension

3.1. Fractal Dimension Overview

It is known that stratified network is typical self-similar network [9]. Fig. 2 is stratified network topology. WSN is one of stratified network, therefore, the fractal dimension could be used in WSN analysis.

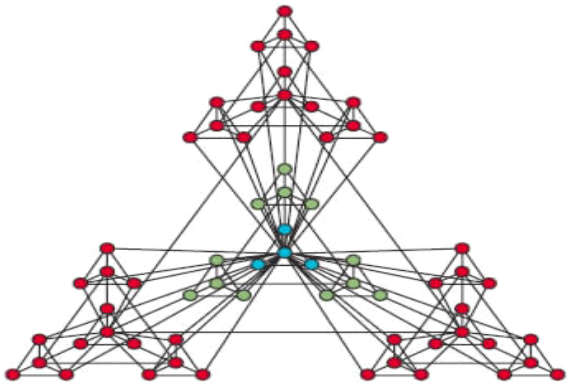

Fig. 2. Stratified network is typical self-similar network.

The fractal dimension can help to understand the topology of the network, and contribute to the construction of the reasonable network topology. In one network, a region with a high value of dimension means a higher complexity of the data and the network attributes in this region, which represents as the nodes concentrated, high energy consumption and large difference of measurement value. A region with low value of dimension is known as lower complexity of the data and network topology, which means the nodes highly dispersed, low energy consumption and small difference of measurement value. The fractal dimension would contribute to determine which cluster needs to be adjusted. As an analytical tool, fractal dimension would help to describe current network status and provide a basis for network optimization.

3.2. Method for Calculations

The main calculation methods of fractal dimension include Hausdorff algorithm and box covering algorithm. Box covering algorithm is widely used because it is simple and easy to use. Song and others have researched calculation of dimension about complex network [10].

To calculate the geometry dimension, a box with side length L is using to cover the geometry graphic. The $N_B(L_B)$ is the minimum number of boxes needed to completely tile a given graphic with boxes of lateral size L_B. The box dimension can be multi-dimensional, as a line describes one dimension, a plane describes two dimensions, and a cube describes three dimensions. The box dimension formula is:

$$D_B \approx -\frac{\ln(N_B(L_B))}{\ln(L_B)}, \quad (1)$$

Equivalent power-law formula:

$$N_B(L_B) \approx L_B^{-D_B}, \quad (2)$$

Fractal dimension reflects the statistics of degree of space filling, and reflects the complexity of space.

4. Optimization STEPS Based on Fractal Dimension

In order to calculate actual network dimension by using box covering algorithm which needs to be refined because fractal dimension defined in Euclidean Space not exist in actual environment, and the L of box covering formula is not the Euclidean distance between two nodes in actual environment. In additional, the traditional box dimension algorithm selects node equally no matter the node is a cluster head or not. However, in actual calculation process, the nodes should be distinguished for selection because the WSN cluster node information saves in the cluster head.

This paper proposes the following optimization steps:

i. Calculate the dimension of cluster D_B.

ii. Compare the value of cluster dimension and threshold.

a) When the value of cluster dimension is higher than the threshold, it means that the complexity value of cluster is higher. Such situation needs to add more nodes for monitoring. In order to obtain more effective data of the sensing region, it needs to add adjacent nodes;

When the value of cluster dimension is less than the threshold, it means that the complexity value of cluster is lower. Such situation needs to reduce online nodes. In order to be more effective and reduce energy consumption, the redundant nodes will be set sleep.

After optimization, the number of node deployed in different region would be adjusted. The efficiency of the whole network will be increased, the energy consumption will be reduced, and the network life time will be extended in this way.

5. Algorithm Description

5.1. Network Model

In order to illustrate the practicability of the algorithm, it needs to create a network model. In this model, the sensor nodes are randomly distributed in a square region and assume the following:

i. The nodes are randomly distributed and monitoring environment may change at any time;

ii. Any node has unique identifier and isomorphic;

iii. Sensor nodes would not move after installation;

iv. Base station is deployed far away from monitoring region;

v. The nodes is not aware of the location themselves, but could calculate the distance according to the received signal strength from cluster head or other adjacent nodes;

The premise of algorithm is assuming N nodes in the cluster, the count of round calculation from 1 to i until the network expire.

5.2. Improvement of Dimension Algorithm

The structure of cluster may affect the whole network performance. Good cluster structure not only can reduce the energy consumption of the network, but also can obtain more accurate monitoring data of the network.

In the covering boxes algorithm, the different covering boxes have different number of nodes. Traditional box covering algorithm does not consider the number of nodes covered by each box. However, it needs to be reflected as a parameter of complexity calculation, because the box covered more nodes means the network is more complex. Meanwhile, one box with a lot of nodes means such nodes measurement values may be very similar to each other. For these reasons, the complex network could be optimized by reducing the complexity of the network, such as to set some nodes sleep to reduce the complexity which also helps to reduce the energy consumption and extend the network lifetime.

The box dimension algorithm is improved by calculating the number of nodes covered in each box. This method can also be used to calculate the dimension of measurement difference of nodes. The changes to box covering algorithm is as following:

i. Numbering each box according to the degree of its filling (the number of nodes covered by one box). The measurement difference between the node

and head node can also be used as an object of box covering.

ii. Calculating the probability $P_i(r)$ of measurement difference covered by i box:

$$P_i(r) = \frac{N_i(r)}{N(r)}, \tag{3}$$

iii. Deriving the measurement difference from formula below:

$$I(r) = -\sum_{i=1}^{N(r)} p_i(r) \log p_i(r), \tag{4}$$

iv. Deriving the new dimension calculation formula based on formula (3), (4):

$$D_i = \lim_{r \to 0} \frac{I(r)}{\log(\frac{l}{r})}, \tag{5}$$

5.3. Pseudo Code

Pseudo code of the program to reduce the complexity of cluster is as follow:

Pseudo code of calculate D_i describe as follow:

While (i)

{

Float r , D , $T_n[]$, T_i , T_n , D_i , C_i ;

//define round number, dimension, difference of measurement value, head node value, dimension of i round//

$T_n[] = C_i$;

//in round of i , n of nodes needed is used to calculate the difference of the measurement value between head nodes and other nodes saved in array $T_n[]$. Each measurement value saved in array $T_n[]$ is different between cluster head node and non-head nodes.//

While ($n = 1$)

{

$T_n[n] = fabs(T_n - T_C)$

//calculate the difference and save in array $T_n[]$ //

$P_n[r] = T_n[n] / T_c$

//calculate the probability $P_n(r)$ under reference value//

}

$I(r)$;

// calculate $I(r)$, sum the product of the logarithmic;//

D_i ;

//Calculate dimension D_i , judging whether there is higher dimension value based on D_i . If exit, then recreated cluster at the next round and added more nodes; if dimension is small then selected few nodes act as agent and the other nodes enable sleep. //

If ($D_i > D$)

// If dimension is greater than the threshold D , it means that cluster is more complex and the difference inside cluster is more complex. The cluster structure needs adjustment at the next round to reduce complexity.//

Else if ($D_i < D / 2$)

// If dimension is less than the threshold, it means that cluster structure is simple, the difference inside cluster is smaller, it could select some nodes to sleep until next round.//

// enter steady-state transmission.//

}

5.4. Discussion

Add the improved dimension algorithm into clustering algorithm could be used to optimize the complexity of the WSN. The optimization approach is divided for two steps below:

i. Calculating the cluster dimension D_B in the network through formula (1). Calculate the dimension of each cluster according to the measurement distance between nodes to the cluster head. The distance between node and cluster can be obtained through the strength of signal from node to cluster head. In formula (1), the side value of box is L , and the value of L refers to threshold d_0 in energy consumption model of WSN [11].

$$E_{Tx}(l,d) = \begin{cases} l(E_{elec} + \varepsilon_{fs} d^2), d < d_0 \\ l(E_{elec} + \varepsilon_{mp} d^4), d \geq d_0 \end{cases}, \tag{6}$$

ii. Calculating the cluster dimension D_i in the network through formula (5).

Analyzing the relationship between two dimensions:

i. If $D_B = D_i$, it means that space distribution is consistent with measurement value distribution. If the number of nodes in each box is 1, it means the node reached the maximum utilization and all the nodes measured effectively. If the number of nodes in each box is bigger than 1, then only kept 1 node and the others all go to sleep mode.

ii. If $D_B \neq D_i$, it means that space distribution and measurement value has not uniform distributed. According to the fractal dimension theory, there is always $D_B \geq D_i$. When $D_B > D_i$, it illustrates that the

measurement value of some cluster nodes is too close to each other. It can be adjusted by changing the number of nodes in the cluster and retain effective nodes. Or can be adjusted by changing the distance of nodes or increase the adjacent nodes to reduce dimension value of D_B.

In practical application, D_B is changed with L and D_i is changed with threshold of the difference of measurement value. Therefore, the complexity can be reasonable optimized by selecting L and threshold based on the practical requirements.

5.5. Algorithm Analysis

The algorithm optimization proposed in this paper is different from the ordinary algorithm optimization. The low energy algorithm (LEA) considered the monitoring environment has changed after a period of time when the WSN has been deployed. By using dimension calculation and complexity analysis could help to understand network more objectively and to provide guidance for the subsequent optimization.

About complexity of algorithm, traditional box covering algorithm relies on the node initial sequence as Song proposed [12, 13], but the initial sequence is randomly allocated, and there are multiple possibilities of node covered by box. The node be covered is also randomly allocated. The traditional box algorithm can be considered as an exhaustive attack method. The complexity of algorithm is $O(n^2)$, and lots of nodes meet the conditions, the node will randomly select. The process of "box covering algorithm" similar to greedy coloring algorithm, the complexity of coloring algorithm has been described in detail at the paper of researchers [14].

Unlike random node selection of Song's box covering algorithm, the initial sequence of nodes in the optimization algorithm in this paper is decided by the cluster information stored in the cluster head. The subsequent node will be covered according to the sequence stored in the cluster head during the box covering process. Non-cluster nodes no longer execute "box covering" mutually. This approach avoids the random selection of nodes in initial phase. The complexity of calculation of D_B is $O(n)$. The complexity of calculation of D_i is still $O(n)$ because the second calculation step follows the first dimension calculation completed. This will cause the complexity unchanged.

Since the LEA algorithm applied based on the original clustering algorithm, it will affect the complexity and efficiency of the algorithm. Comparing with LEACH algorithm, in the condition of network with smaller number of nodes and simple structure of clusters, the LEA algorithm will increase the computational task. Along with the development of WSN, there will be an increase in the number of nodes. The LEA algorithm provides a way of selecting part of the nodes into sleep which will consequentially extend the network overall life cycle. The dimension-based optimization should be utilized in the condition of the cluster structure changes or the measurement environmental changes.

6. Simulation Results

Using MATLAB, we simulate a WSN in an area dimensions 500×500 m. All 100 and 500 nodes are randomly distributed over the field.

Fig. 3 and Fig. 4 show graphs of WSN alive nodes result between LEACH, LEACH-C and optimization algorithm. We notice that the optimization algorithm extend longer node life than LEACH and LEACH-C. The first node dies and the last node dies extended about 30 %. This means that optimization algorithm is more efficient than LEACH for that highly benefit from reducing complexity.

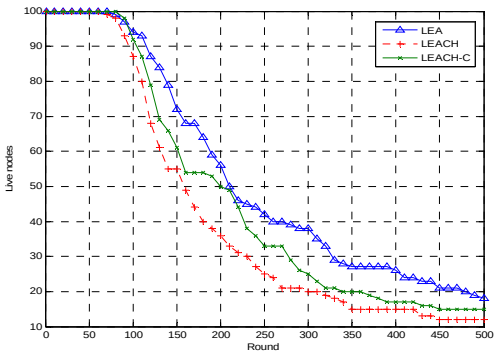

Fig. 3. The number of live nodes (100 nodes).

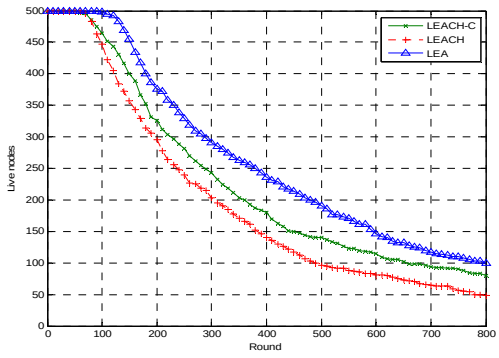

Fig. 4. The number of live nodes (500 nodes).

6. Conclusions

In this paper, the use of dimension algorithm is proposed as an optimization idea and method for WSN. Taking the WSN as a kind of complex network, the paper proposed to utilize fractal dimension algorithm to calculate the different measure dimension of cluster, and analyzed LEA algorithm. Simulation results show that LEA

prolongs the network lifetime compared to LEACH and LEACH-C, so the total energy is efficiently consumed. There may still have been trends apparent within the results. These could be a valuable guidance for future study.

Acknowledgements

The work presented in this paper was supported by the National Natural Science Foundation of China (Grants No. NSFC-61170176), Fund for the Doctoral Program of Higher Education of China (Grants No. 20120005110002), National Great Science Specific Project (Grants No. 2012ZX03005008, 2012ZX03003006) and Beijing Municipal Commission of Education Build Together Project.

References

[1]. R. Gupta, K. Sultania, P. Singh, Security for wireless sensor networks in military operations, in *Proceedings of the 4th International Conference on Computing, Communications and Networking Technologies (ICCCNT)*, 2013, pp. 1-6.

[2]. B. B. Mandelbrot, Fractals: Form, chance and dimension, *Freeman*, San Francisco, 1977.

[3]. M. Niswar, A. A. Ilham, E. Palantei, Performance evaluation of ZigBee-based wireless sensor network for monitoring patients' pulse status, in *Proceedings of the International Conference on Information Technology and Electrical Engineering (ICITEE)*, 2013, pp. 291-294.

[4]. R. H. Wendi, C. Anantha, B. Hari, Communication protocols for wireless sensor networks, in *Proceedings of the IEEE Hawaii International Conference on System Sciences*, 2000, Vol. 8, pp. 4-7.

[5]. Ioannis Ch. Paschalidis, R. M. Wu, Robust maximum lifetime routing and energy allocation in wireless sensor networks, *International Journal of Distributed Sensor Networks*, 2012.

[6]. Anfeng Liuyz, Z. M. Zheng, C. Zhang, Z. G. Chen, X. M. Shen, Secure. energy-efficient disjoint multi-path routing for WSNs, *IEEE Transactions on Vehicular Technology*, Vol. 61, Issue 7, 2012, pp. 3255-3265.

[7]. Haibin Yu, Peng Zeng, Intelligent wireless sensor network system, *Science Press*, Beijing, 2006.

[8]. H. Wendi, C. Anatha, B. Hari, An application-specific protocol architecture for wireless microsensor networks, *IEEE Transactions on Wireless Communication*, Vol. 1, Issue 4, 2002, pp. 660-670.

[9]. K. Tadaki, The Hausdorff dimension of the halting self-similar sets of T-universal prefix-free machines, in *Proceedings of the International Conference on Information Theory Proceedings (ISIT)*, 2010, pp. 1287-1291.

[10]. Chaoming Song, Lazaros K. Gallos, Shlomo Havlin, Herńan A. Makse, How to calculate the fractal dimension of a complex network: the box covering algorithm, *Journal of Statistical Mechanics*, 2007, P03006.

[11]. V. V. Deshpande, A. R. Bhagat Patil, Energy efficient clustering in wireless sensor network using cluster of cluster heads, in *Proceedings of the International Conference on Wireless and Optical Communications Networks (WOCN)*, 2013, pp. 1-5.

[12]. Song Chao-ming, S. Havlin, H. A. Makse, Self-similarity of complex networks, *Nature*, Vol. 433, 2005, pp. 392-395.

[13]. Song Chao-Ming, L. K. Gallos, S. Havlin, et al, How to calculate the fractal dimension of a complex network, The box covering algorithm, *Journal of Statistical Mechanics*, 2007, P03006.

[14]. Yao Shang-Lin, Qin Sheng-Gao, Wang Guo-Hui, Multi-fractal fractal characteristics of the heterogeneous pore distribution of cores, in *Proceedings of the International Conference on Computer Distributed Control and Intelligent Environmental Monitoring (CDCIEM)*, 2012, pp. 424-427.