Journal of Computers Vol. 27, No. 4, 2016, pp. 29-39
doi:10.3966/199115592016122704003

Detect and Reuse Redundant Nodes for Media Access Contral Address Assignment Algorithm in Wireless Sensor Networks

Xiang-qian Wang[1], Bin Ge[2*], Jian-Bao Zheng[2], and Yue Han[2]

[1] School of Economics and Management, Anhui University of Science & Technology
Huainan, Anhui, 232001, China
xqwaust@163.com

[2] School of Computer Science and Engineering, Anhui University of Science & Technology
Huainan, Anhui, 232001, China
bge@aust.edu.cn, {117334734, 526774363}@qq.com

Received 14 April 2015; Revised 15 June 2015; Accepted 28 August 2015

Abstract. In order to reduce the energy consumption caused by node address and send message in wireless sensor network, detection and reuse redundant nodes for media access control (MAC) address assignment algorithm in wireless sensor networks (WSN) was proposed. In this algorithm, the MAC address was divided into cluster address and inner-cluster address by using address multiplexing ways. Detecting redundant nodes and making it dormant before inner-cluster address assignment. In this way, the number of nodes involved in assigning address and the energy consumption of sending message were reduced. Then, the inner-cluster address is assigned with different lengths according to remaining energy and the number of neighbors of a node. When the network updates address, redundant nodes can be used to replace of the death node. Simulation results show that the proposed algorithm can efficiently decrease the average address length and communications volume, and extend the lifetime of the network.

Keywords: address assignment, clustering, network lifetime, redundant nodes, WSN

1 Introduction

As the technology of wireless sensor network (WSN) [1-4] was becoming more and more mature, it had a significant influence in many field, such as national defense military, medical and health and ecological environment monitoring, at the same time, it also promoted the further development of WSN technology. It is a kind of brand-new information acquisition and processing platform, which integrate the ability of perception, computing and wireless communication. The research status of WSN mainly concentrated is extending the network lifetime [5-6]. In WSN, because the volume of sensor nodes is generally small, which always carry the limited battery power [7], and due to the complexity of deployment environment and huge quantity of nodes, it is unrealistic to replace the battery. Therefore, reducing the size of a transmission packet as much as possible that can reduce energy consumption of the nodes, which plays a vital role in extending the lifetime of the whole network. Research shows that the energy consumption of WSN is mainly caused by the process of wireless communication [8-9]. One bit of data transfers energy greater than the node processing information energy [10]. Due to each packet carries a small amount of data in wireless sensor networks, generally only 8 bit to 16 bit, MAC address often accounts for a significant proportion in the communication overhead. And compared with the data fusion technology to reduce data load, the overhead of MAC address in data transmission is particularly prominent [11]. Therefore, reducing the length of MAC address and the amount of control information in the process of address assignment, which has very important significance in reducing the energy consumption of node communication, prolong the service life of nodes and the lifetime of whole wireless sensor networks.

* Corresponding Author

According to the address representation can be divided into fixed-length address and variable-length address. Fixed-length address is relatively simple, and variable-length address can adjust the address space, more flexible. But, the average length of fixed-length address is much longer than variable-length address in large-scale network. Therefore, using variable-length address is more suitable for wireless sensor networks.

At present, the researches of wireless sensor network node address allocation is mainly aiming to reduce the length of MAC address and the control information exchange, which have made some good progress. The study distributed unique global ID assignment for sensor networks was proposed [12]. This algorithm calculates network size by tree structure and assigns a globally unique address for nodes. The advantage is that this algorithm can complete large-scale network address assignment in a relatively short period of time, and the disadvantage is that there is inevitably large address length. MAC address assignment algorithm using static game model in WSN—MAAS (MAC address assignment based on static game model) was proposed [11]. The algorithm modeled sensor nodes as decision-maker in the game model MAAS, which assigned local unique MAC address based on the Nash equilibrium in the game model. Although the nodes according to neighbor nodes information to make decisions independently to avoid sending a large amount of information exchange between nodes, have reduced the energy consumption in the communication process, however, there are still exist certain address conflict. A distributed algorithm based on geographic location—VGSR (virtual grid spatial reusing) was proposed [13]. In this algorithm, the node according to its geographical location coordinates calculation MAC address, also avoid sending a large amount of information exchange between nodes, and have reduced the energy consumption in the communication process. However, the algorithm is suitable for network nodes distributed uniformly, while nodes uneven distribution will be address conflict phenomenon. In [14], a dynamic address assignment algorithm based on cluster—CDAA (cluster-based dynamic address assignment) was proposed. The algorithm using clustering and address multiplexing technology to reduce the average length of the nodes MAC address, which avoid the address conflicts between nodes. But in the process of address assignment within the cluster, it consumes a lot of energy when exchanging information.

In this paper, based on the above research and aimed at reducing the length of the MAC address and the control information in the process of address assignment, an improved dynamic address assignment algorithm that based on cluster was proposed. Because the number of wireless sensor network nodes was numerous, and they were distributed randomly, there will be some redundant nodes in the network [15]. During the process of address assignment, the redundant nodes will lead to increasing of the average length of each cluster node address, besides; it also increases a large number of information exchanges and the energy consumption in each node of the wireless communication.

Firstly, this paper introduces the MAC address multiplexing technology, and uses it to divide the cluster and assign address. Then, the inner-cluster addresses assignment process, processing all inner-nodes, and using redundant nodes judging method to detect and make them dormant, after that proceeding inner-cluster address assignment. However, when the inner-cluster address is updated, if the node was dead, the node is replaced with adjacent redundant nodes. Finally, lots of computer simulations and analysis had been done. The algorithm proposed in this paper further decreases the length of MAC address nodes and the amount of information exchange between nodes. At the same time, it enables the redundant node to replace the dead node and therefore effectively extends the lifetime of the entire network.

2 MAC Address Spatial Multiplexing Technology

In the MAC protocol header field, the length of the MAC address is very considerable, and the assignment of the MAC address usually uses globally unique allocation methods. With the increase of network scale, its length is increased. Therefore, the length of the MAC address need to reduce. Aimed at this problem, the MAC address spatial multiplexing technology can be used. Node addresses are multiplexed using regional grid segmentation, which on a regional basis.

WSN adopt the method of multi-hop wireless communication for data transmission. In the process of communication, the main purpose of the MAC address is to define data frame in each hop transmission of sending and receiving nodes, therefore, the node MAC address just request unique at local scope and in different area can be reused [16].

In WSN, let r_c be the node communication radius and d be the node distance between i and j. If

$0 < d \le r_c$, then the nodes *i* and *j* will become complementary hop neighbor nodes; if $r_c < d \le 2r_c$, then the nodes *i* and *j* will become complementary two-hop neighbor nodes; if $d > 2r_c$, then the nodes do not interfere with each other in this area.

As shown in Fig. 1, Communication between node 1 and node 4 do not interfere with each other, but will be between node 1 and node 2, 3. The node 2, 3 is in the two-hop range of node 1, and the node 4 on the outside. The figure shows, When node 2 or node 3 and node 1 using the same MAC address, it will produce conflict, and can not be distinguished from each other. But the node 4 and node can use the same MAC address D_1. The reason is that the MAC address mainly uses to identify sending node and receiving node at each hop of communicating data frames.

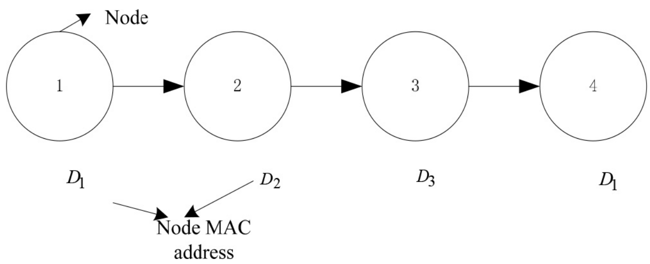

Fig. 1. MAC address multiplexing

Therefore, with regard to the MAC address of any nodes, it can be reused out of its two-hop range, however, it is negative when it in the range. In accordance with this characteristic, sensor network can be divided into multiplexing areas. The multiplexing area division and address assignment method will be elaborated in section 3.3

3 Improved Address Assignment Algorithm Based on Cluster

In this algorithm, the MAC address of each node consists of two parts: cluster address and inner-cluster address. Firstly, according to the location of nodes' coordinates calculated cluster address. And then, cluster center node assigned inner-cluster address. Finally, the two parts constitute the whole MAC address.

3.1 Cluster division and cluster address assignment

WSN consists of a large number of sensor nodes, let r_c be the nodes communication radius (communication radius usually is far more than two times of sensing radius), then the maximum distance between two hops is $2r_c$.

Step 1: Square cell division. Firstly, clustering the nodes of the network and using square partition method to divide the clusters boundary. Now with *a* as the side length to divided the sensor node distribution area into a square cell connected closely, each square cell contains a lot of nodes, and these nodes form a cluster, have the same cluster address. Let *n* be the average number of nodes in each cell, *S* be the area of node distribution area, and *N* be the nodes total number. Their relationship is $\frac{S}{a^2} = \frac{N}{n}$, then

$$a = (nS/N)^{\frac{1}{2}} \quad (1)$$

Therefore, in the condition of known network area and the total number of nodes, *a* size can be set according to expected the average number of nodes in each cell. In order to make the distance between nodes having the same cluster address exactly over $2r_c$, here take $a = 0.7r_c$.

Step2: Multiplexing area division. Multiplex distance is the distance between two nodes can multiplex the same address, let d_r be the multiplex distance. Using the method of space address multiplexing, with d_r as the side length to divided all cells into a square multiplexing area, as shown in Fig. 2. These cells form cell cluster together (Rough wireframe representation). Then the multiplex distance with the cell side length relationship can be expressed as:

$$d_r = (Int(2r_c / a) + 1)a \qquad \textbf{(2)}$$

Where *Int*( ) is the rounded up operation, calculated

$$d_r = 4a = 2.8r_c \qquad \textbf{(3)}$$

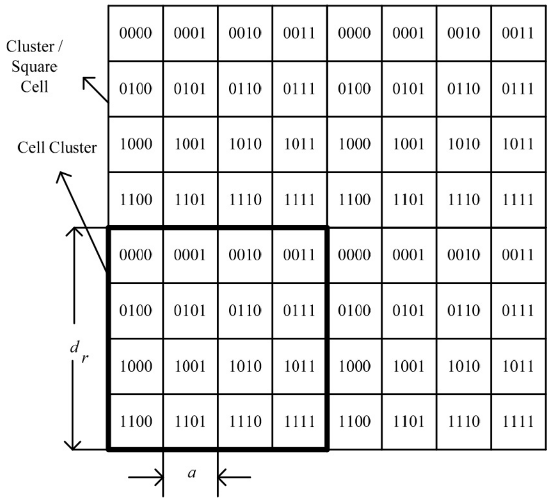

Fig. 2. Cluster division and cell cluster

Step 3: Cluster address assignment. The cells within multiplexing area are assigned different cluster address according to their geographic location, cell clusters contains 16 clusters (Square Cell), which only need 4 bits to represent cluster address, Such as $0000, 0001, 0010, \cdots 1111$. Clusters (Square Cell), which position corresponding to neighboring cell cluster, has the same cluster address. The figure shows that the distance between nodes having the same cluster address is greater than the 3*a*, while $3a = 2.1r_c$. Just to meet that any node's MAC address could be reused out of the range of the two-hop range.

3.2 Redundant nodes within the cluster detection

To detect redundant nodes within the cluster before inner-cluster address assignment.

Node redundant technology can significantly improve the performance of WSN, under the condition of monitoring area completely covered make redundant nodes dormant, can save a lot of energy [17], and can wake redundant nodes up to instead of death nodes [18].

WSN generally adopt the random deployment, and the number of nodes is huge, so there are a lot of redundant nodes. If the node detection area can be completely covered by its neighbor node, the node is a redundant node. According to the previous section, cluster is a square cell with $a = 0.7r_c$ as side length. Therefore, all the nodes in the cluster are all within the communication range. And detection radius of sensor nodes r_s is generally smaller than their communication radius r_c. Therefore, according to detecting radius of nodes determine neighbor node in this paper.

Set node detection radius as r_s, then the detection area is a circular area of radius r_s, denoted as $S(i)$ and area denoted as S_i. Located in the node area are neighbor nodes, the neighbors of node *i* is denoted as $N(i)$ and the number denoted N_i. As shown in Fig. 3, Neighbor nodes *i* and *j* detection area intersect at two points O_1, O_2 result in overlapping coverage in $S(i)$ and $S(j)$. Overlapping coverage area is simplified as fan-shaped area by iO_1, jO_2 and O_1O_2, denoted by $S(i, j)$ and area denoted S_{ij}. The area is calculated as follows:

$$S_{ij} = \theta(r_s)^2 \quad \textbf{(4)}$$

If

$$\bigcup S(i,j) \supseteq S(i), j \in N(i) \quad \textbf{(5)}$$

And

$$\sum_{1}^{N_i} S_{ij} \geq S(i) \quad \textbf{(6)}$$

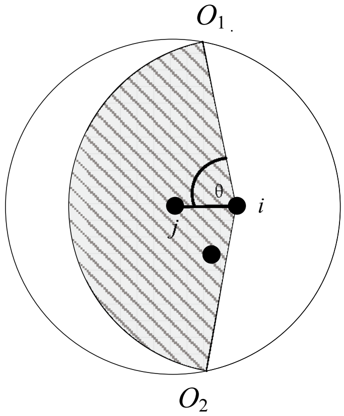

Fig. 3. Node overlapping coverage schematic

Then the node detection area is completely covered by its neighbor nodes, and was judged to be redundant nodes and into hibernation. As shown in Fig. 4, node 0 detection area is completely covered by its neighbor nodes 1, 2, and 3, and regarded as redundant nodes.

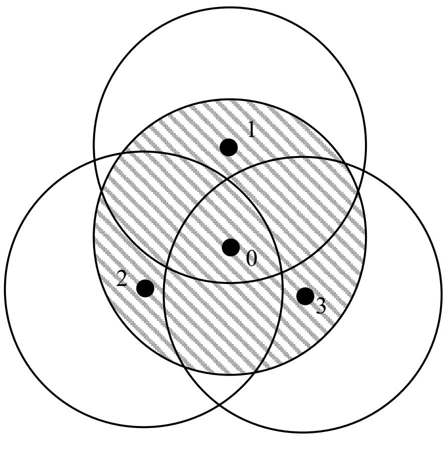

Fig. 4. Detection area completely covered Schematic

Detecting the redundant nodes in the cluster to make its dormant, which decreased the number of nodes involved in assigning address and the average address length. At the same time, it reduced the additional energy consumption of sending message between nodes and redundant nodes. Therefore, redundant nodes judgment within the cluster can greatly improve energy efficiency and extend the entire network lifetime.

3.3 Inner-cluster address assignment

Inner-cluster address assignment is the assignment of each node of cluster.

According to the previous section, node in the other node detection area was regarded as neighbor nodes. Let ω_i, $E_i(t)$ and N_i be the Node Scale Factor, node residual energy and neighbor node number, then ω_i can be calculated as follows:

$$\omega_i = \frac{N_i}{E_i(t)}, i = 1, 2, \cdots, N \quad \textbf{(7)}$$

First of all, compare with the residual energy of the working nodes in the cluster and take the biggest energy node as the central node undertaken address assignment tasks. Then, compare the working node scale factor. A big scale factor exist two kinds of situation, the first is the residual energy of nodes are small; the second is the neighbor nodes number are large, in this situation, communication will be more frequently and energy consumption will be more. Therefore, no matter under the any circumstance, the larger the scale factor is assigned to the node address is shorter, the smaller the scale factor is assigned to the node address is longer. Address sorted by length from small to large, such as 0,1,00,01,10,11….

By this time, cluster address and inner-cluster address have been assigned, the rest of the work just combine them together, which can get the complete MAC address. By using the method of space address multiplexing, can make full using of the address space is sufficiently utilized. Compared with node scale factor, considered with the residual energy and communication capabilities for node assign the appropriate address length, and effectively improve the utilization of Node energy. Detect the redundant nodes in the cluster and make it dormant, further reducing the average inner-cluster address length and node communications volume.

3.4 Inner-cluster address update

In wireless sensor networks, some nodes died because of excessive energy consumption. When death nodes reach a certain percentage, the entire network is considered to be death [19]. Due to the center node within the cluster undertake the task of address assignment and forwarding information, its energy consumption more than other nodes. The neighbor nodes number of each node is different, the neighbor nodes number larger, the communication ability is stronger, and the energy consumption is also more. After a period of time, the residual energy of the nodes in the network will become large differences, and the scale factor will change dramatically. Therefore, it is necessary to reselect the center node and reassign the appropriate address length.

Inner-cluster address updates process shown in Fig. 5.

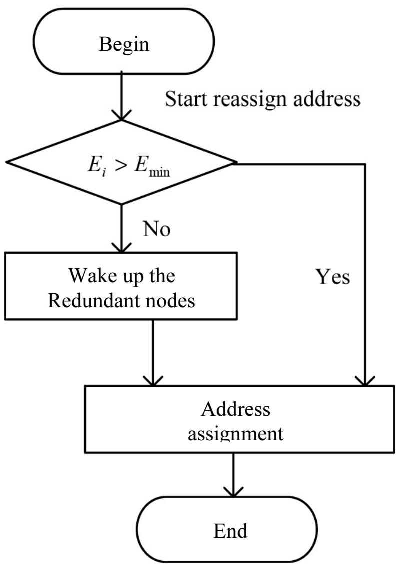

Fig. 5. Address update flowchart

Finally, when reassigning address, check the residual energy of all nodes and choose the node with the largest residual energy as the center node. Node residual energy is less than the allowed minimum $E_{\min}$, it represented the node was died, and it will be removed from the network. If neighbor nodes of death node have redundant nodes, waking up the redundant nodes to replace death nodes, and then reassign address. If the node residual energy is greater than $E_{\min}$, directly reassign address.

With regard to update the inner-cluster, it reduced some nodes excessive energy consumption and balanced the energy consumption of each node, waking up redundant nodes to replace death nodes, which extend the network lifetime and ensure the network coverage to a certain extent.

3.5 Communication energy consumption

The energy consumption of sensor nodes includes sensing, data processing and communication consumption, while the communication consumption much more than the other two. Let l_i and l_j are the length to node *i* and *j* respectively, then the energy required by node to transmit l_{mess} -bit message over a distance *d* between node *i* and *j* is given as follows:

$$E_{Tx}(l,d) = lE_{elec} + l\varepsilon_{amp}d^{\alpha} \quad \textbf{(9)}$$

Where $l = l_i + l_j + l_{mess}$, E_{elec} is the unit energy consumption of RF circuits sending or receiving data, ε_{amp} is the power amplifier parameters and α is the path loss index.

The energy required by the node to receive an l_{mess} -bit message is given as follows:

$$E_{Rx}(l) = lE_{elec} \quad \textbf{(10)}$$

Therefore, the total communication energy consumption is calculated as follows:

$$E = E_{Tx} + E_{Rx} \quad \textbf{(11)}$$

4 Simulation Results

From aspects of address assignment in the process communication energy consumption and average address length by using MATLAB, which can evaluate the performance of proposed algorithm. The *N* nodes of experiment simulation will be distributed in *L*L* square area randomly. The results of experiment were the average of 100 times simulating under the same conditions.

Firstly, Let *L*=1000 m, the value of *N* range from 1000 to 10000, with amplification of 1000. Besides, under the conditions of communication nodes' radius of 100 m, analyzing the average address length change with node number in the each algorithms. As shown in Fig. 6, the average length of algorithm in this paper was minimum, however, because the algorithm of VGSR adopted same length of global address assignment, the average length of address was longest. The algorithm of MAAS and CDAA adopted space address multiplexing technology and the structure of variable length. But in the process of address assignment, the algorithm of MAAS will lead to the result of address conflicting, so the algorithm of MAAS average address length was longer than the algorithm of CDAA. Besides, relative to the algorithm of CDAA, when the algorithm of this paper was proposed in the assignment of inner-cluster address, the first step was detecting redundant nodes and making it dormant. Therefore, the number of node participating in assigned of address will be decreased, thus reducing the average length of network nodes. At the same time, the average length of network nodes will increase with the number of nodes.

Fig. 7 shows that under the range of the same density of nodes, changing coverage of network, and the average length of network nodes address changing. As shown in (Fig. 6), every kinds of algorithm of the average address length did not change significantly, for the reason of adopting space address multiplexing technology. The algorithm of VGSR was adopted same length of global address allocation methods, so the average address length was longest. Besides, relative to the algorithm of MASS, when the proportion of network was small, due to the address of CDAA algorithm, which was divided into clusters address and inner-cluster address, however, the length of clusters address was fixed, so the average address length of CDAA was longer. But when the scale of network increasing, the average address length of MASS will be increasing and it will be greater than the algorithm of CDAA. The proposed algorithm in this paper based on the CDAA, eliminating redundant nodes and do not assign address for redundant nodes, the result is that it further reduces the average length of network nodes.

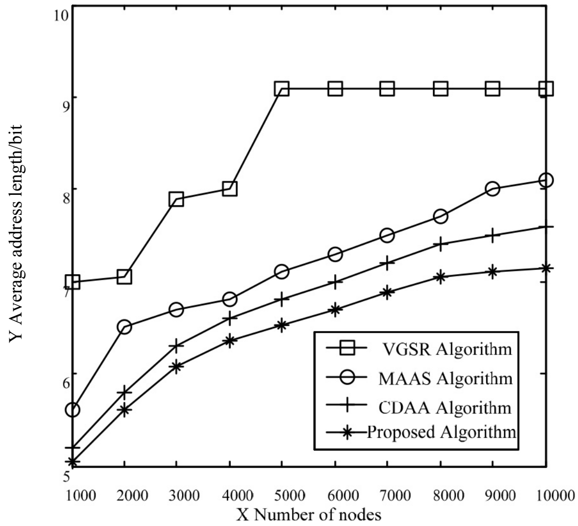

Fig. 6. Different number of nodes corresponding average addresses length

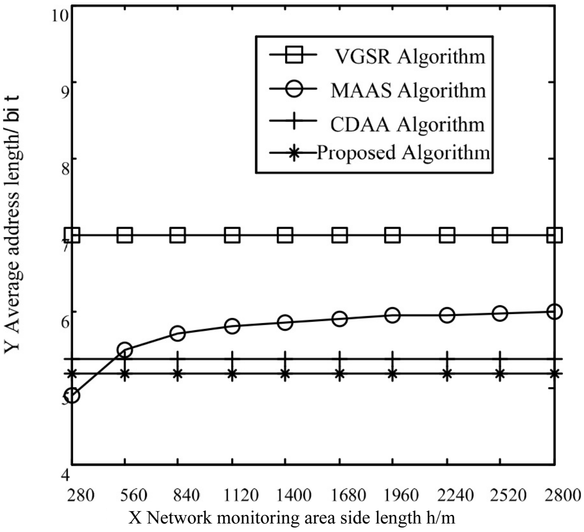

Fig. 7. Different network monitoring area side length corresponding average addresses length

In Fig. 8, let L=1000 m, the value of N range from 1000 to 10000, with amplification of 1000. With the increasing number of nodes in the network, the energy consumption of the algorithm of VGSR and MAAS was more, because, it exists address conflicting when they assign the address. Besides, the average address length was long. The algorithm of CDAA and the algorithm proposed of this paper, which were consume less energy, because there was no conflicting of address and the shorter of average address length. In addition, the algorithm proposed in this paper on the basis of CDAA eliminated redundant nodes, reduced the average nodes address length and avoid the energy consume of sending message between nodes and redundant nodes. Therefore, the communication energy consumption was reduced greatly.

As shown in Fig. 9, for the shortcoming of CDAA, the proposed algorithm has improved, and extended entire network lifetime. The proposed algorithm in this paper, when assign the inner-cluster address, detecting redundant nodes and making it dormancy. At the same time, when the inner-cluster address was updating, waking redundant nodes to replace death nodes. While with the number of nodes increasing gradually, the existence of redundant nodes may increase. Meanwhile, it may cause a lot of extra energy consumption. As shown in Fig.8, the algorithm of this paper was effectively extended the entire network lifetime.

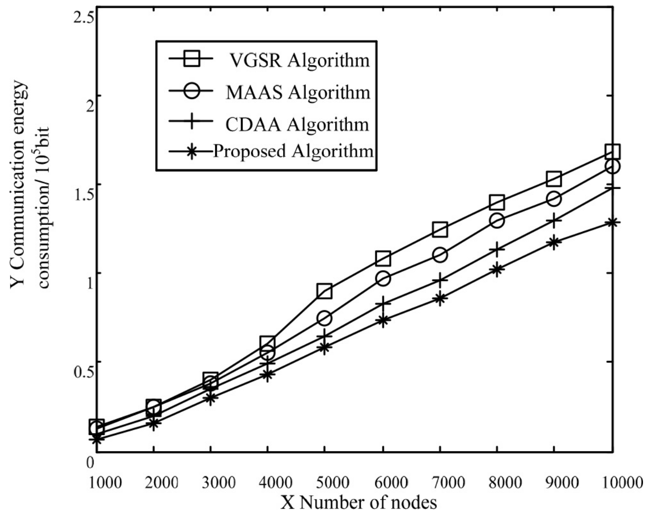

Fig. 8. Different number of nodes corresponding communication energy consumption

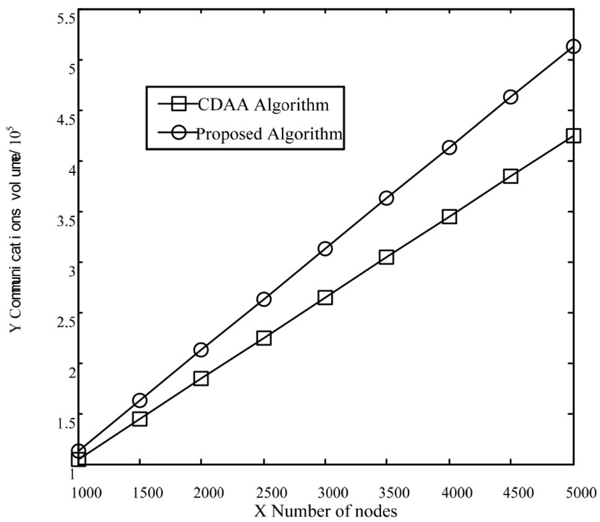

Fig. 9. Different number of nodes corresponding network lifetime

5 Conclusion

For the process of assigning MAC address in wireless sensor network, due to the problem of a larger amount of energy consumption, when exchanging information between nodes and the nodes address length, an improved dynamic assignment algorithm based on cluster was proposed. The algorithm was introduced redundant nodes into monitoring, which decreasing the number of nodes that involved in assignment, at the same time, it avoids energy consumption of sending message between nodes and redundant nodes. On the one hand, the node average address length was reduced; on the other hand, the expense of communication was reduced. In addition, when updating inner-cluster address, waking redundant nodes to replace death nodes. The simulation results show that: the algorithm reduced the network energy consumption and extended the entire network lifetime. In this paper, although the proposed algorithm decreases the average address length and communications volume, the redundant nodes detection method needs to be improved. The further study is to optimize the method of redundant nodes detection and reduce the algorithm complexity.

Acknowledgement

This work was financially supported by the National Natural Science Foundation of China (61070220, 61170060), Anhui Provincial Natural Science Foundation of China (1408085ME110), Anhui Provincial Major Project of Colleges and universities Natural Science (KJ2013ZD09) and Anhui Provincial Key Project of Colleagues and universities Natural Science (KJ2012A096).

References

[1] L. Anchora, A. Capone, V. Mighali, L. Patrono, and F. Simone, A novel MAC scheduler to minimize the energy consumption in a wireless sensor network, Ad Hoc Networks 16(2014) 88-104.

[2] L. Mottola, G.P. Picco, Programming wireless sensor networks: fundamental concepts and state of the art, ACM Computing Surveys 43(2011) 19-24.

[3] J.G. Yu, Y.Y. Qi, G.H. Wang, X. Gu, A cluster-based routing protocol for wireless sensor networks with nonuniform node distribution, International Journal of Electronics and Communications 1(2012) 54-61.

[4] X.P. Zhang, J.Y. Wang, M.G. Wu, Y. Cheng, A novel spatial clustering with obstacles based on genetic algorithms and K-medics, in: Proc. of the Sixth International Conference on Intelligent Systems Design and Applications (ISDA'06), 2010.

[5] Z.A. Eu, H.-P. Tan, W.K.G. Seah, Design and performance analysis of MAC schemes for wireless sensor networks powered by ambient energy harvesting, Ad Hoc Networks 9(2011) 300-323.

[6] O.D. Incel, L. Hoesel, P. Jansen, P. Havinga, MC-LMAC: a multi-channel MAC protocol for wireless sensor networks, Ad Hoc Networks 9(2011) 73-94.

[7] R.Z. Sun, J. Yuan, L.S. You, X.M. Shan, Y. Ren, Energy-aware weighted graph based dynamic topology control algorithm, Simulation Modeling Practice and Theory 19(2011) 1773-1781.

[8] H.F. Jiang, J.S. Qian, Y.J. Sun, R.K. Sun, J. Li, Energy cost based energy optimized routing algorithm in WSN, Computer Science 39(2012) 73-76.

[9] W.L. Tan, W.C. Lau, O.C. Yue, Performance analysis of an adaptive, energy-efficient MAC protocol for wireless sensor networks, Journal of Parallel and Distributed Computing 72(2012) 504-514.

[10] L. Wang, W. Lin, J.M. Huang, Multi-source coalition transmissions with fault tolerant routing for data centric WSNs, Journal of Computers (Taiwan) 25(2014) 20-27.

[11] K. Tu, N.J. Gu, K.X. Ren, MAC address assignment algorithm using static game model in wireless sensor networks, Journal of Chinese Computer Systems 30(2009) 835-837.

[12] E. Ould-Ahmed-Vall, D.M. Blough, B.S. Heck, G.F. Riley, Distributed unique global ID assignment for sensor networks, in: Proc. of IEEE International Conference on Mobile Ad Hoc and Sensor System, 2005.

[13] Y. Tian, M. Sheng, J.D. Li, Virtual grid spatial reusing algorithm for MAC address assignment in wireless sensor network, in: Proc. of the 20th International Conference on Advanced Information Networking and Applications, 2006.

[14] H. Hui, J. Wang, Q. Li, MAC address assignment and updating algorithm for wireless sensor network, Computer Engineering 38(2012) 71-75.

[15] A. Chen, S. Kumar, T.H. Lai, Local barrier coverage in wireless sensor networks, IEEE Transactions on Mobile Computing 9(2010) 491-504.

[16] Y. Tian, M. Sheng, J.D. Li, A novel distributed algorithm for MAC address assignment in wireless sensor networks, Journal of Xidian University 33(2006) 716-720.

[17] Y.H. Liu, L.X. Suo, D.Y. Sun, A.M. Wang, A virtual square grid-based coverage algorithm of redundant node for wireless sensor network, Journal of Network and Computer Applications 36(2013) 811-817.

[18] X.H. Xu, X.Y. Li, X.F. Mao, S.G. Wang, A delay-efficient algorithm for data aggregation in multi-hop wireless sensor networks, IEEE Transaction on Parallel and Distributed Systems 22(2011) 163-175.

[19] A.F. Liu, P.H. Zhang, Z.G. Chen, Theoretical analysis of the lifetime and energy hole in cluster based wireless sensor networks, Journal of Parallel and Distributed Computing 71(2011) 1327-1355.