International Journal of Innovative Computing, Information and Control
Volume **8**, Number **9**, September **2012**

pp. 6037-6047

IMPROVING LIFETIME IN HETEROGENEOUS WIRELESS SENSOR NETWORKS WITH THE ENERGY-EFFICIENT GROUPING PROTOCOL

Jiun-Jian Liaw[1], Lin-Huang Chang[2] and Hung-Chi Chu[1,*]

[1]Department of Information and Communication Engineering
Chaoyang University of Technology
No. 168, Jifong E. Road, Wufong District, Taichung 41349, Taiwan
jjliaw@cyut.edu.tw; *Corresponding author: hcchu@cyut.edu.tw

[2]Department of Computer and Information Science
National Taichung University
No. 140, Min-Shen Road, Taichung 40306, Taiwan
lchang@mail.ntcu.edu.tw

Received May 2011; revised September 2011

Abstract. *Improving the lifetime in wireless sensor networks is important because the sensor nodes in wireless sensor networks are constrained by limited energy. The way to improve a WSN lifetime is to develop energy-efficient protocols for reducing energy consumption. One of the well-known energy-efficient methods is the clustering based algorithm which is designed for homogeneous wireless sensor networks. The clustering algorithms were also improved and applied to the heterogeneous wireless sensor networks. In this paper, an energy-efficient protocol with grouping design is proposed. The proposed method divides sensor nodes into several groups whose total energies are the same. The proposed scheme not only extends network lifetime but is also applicable to the multi-level heterogeneous wireless sensor networks.*
Keywords: Wireless sensor networks, Cluster, Energy consumption, Heterogeneous wireless sensor networks

1. **Introduction.** The rise of informatics drives the rapid development of network and wireless communication technologies [1,2]. Wireless Sensor Networks (WSNs) are increasingly useful [3-6] and are applied to many applications, such as smart living, environmental monitoring, automatic measurement, healthcare, and traffic monitoring. A WSN consists of a large number of sensor nodes, which include small volume, low-cost, limited computation and limited power capacity [7]. The sensor node collects the sensed data by the sensor and transmits the data to an external base station (BS) by wireless communication components. Once the sensor nodes set up to form a WSN, the network continues carrying out the data while the node battery power is sufficient. Minimizing energy consumption for maximizing WSN lifetime becomes a key challenge [8].

In the sensor node, energy is consumed by data sensing, data processing and data transmission. Since the node spends up to 90% overall energy for communication [9], this work focuses on the data transmission method. The transmission protocols can be classified into direct type and indirect type. In the direct type protocol, all the nodes send the sensed data to the BS directly. The node's energy consumption depends on the distance between the node and the BS. The node farther from the BS will die faster [10]. In the indirect type protocol, a node may send the sensed data to another node closer to the BS. Since the distance from the sending node to the forwarding node is shorter than the distance from the sending node to the BS, energy consumption of the sending node can be reduced.

An important indirect type is the clustering scheme [11,12]. Every node is clustered and transmits sensed data to the BS through the cluster head. This process is useful and reduces energy consumption [13-16]. In the clustering approach, the cluster head node collects the sensed data from the nodes in the same cluster and forwards the collected data to the BS. The clustering concept is used to aggregate data to reduce data transmission distance. However, cluster head lifetime is short since the cluster heads are fixed. To improve lifetime, there two popular protocols, LEACH (Low-Energy Adaptive Clustering Hierarchy) [17] and PEGASIS (Power Efficient Gathering in Sensor Information Systems) [18] were proposed.

In the LEACH, cluster heads are not fixed. Each node decides whether it will be a cluster head or not by probability. All nodes take turns as cluster heads. However, the probability makes cluster head distribution non-uniform, and the actual cluster head number may be different from the expected cluster number. The PEGASIS links all nodes into a chain decided by each node or the BS. Each node receives data from its neighbor node, then aggregates and forwards it to the next neighbor node. Compared with the LEACH, the PEGASIS fixes the probability problem and reduces energy expenditure. Since the PEGASIS requires location information of all nodes for chain construction, it is not easy to implement. However, LEACH or PEGASIS does not discern energy discrepancy in the clustering algorithm.

SGCH (Steady Group Clustering Hierarchy) is also a clustering scheme. It considers the energy discrepancy in the cluster head selection [19]. All nodes are uniformly divided into groups (the number of groups is equal to the expected number of clusters). Every group's total initial energy is the same if initial energies of all nodes are the same. In each round, the node with the maximum energy remaining in a group is selected as the cluster head. Observations show that grouping balances the energy consumption and prolongs the WSNs lifetime. However, SGCH, PEGASIS and LEACH are designed for homogeneous WSNs, in which each node's power capacity is the same as that of the others.

In contrast to homogeneous WSNs, heterogeneous WSNs include different types (in terms of initial energy) of sensor nodes [20]. The study of different types of nodes according to initial energy has aroused scholarly interest [11-24], such as SEP (Stable Election Protocol) [25] and DEEC (Distributed Energy-Efficient Clustering) [26]. The SEP is proposed for the two-level heterogeneous WSNs, composed of advance nodes and normal nodes according to initial energy. At the beginning, the advance node's battery is equipped with more energy than the normal node's. However, the SEP is not suitable for multi-level heterogeneous WSNs.

DEEC is designed for multi-level heterogeneous WSNs [26]. The node expends energy uniformly by rotating the cluster head role among all nodes. DEEC chooses cluster heads by the residual energy ratio of the node and average network energy. Cluster head probability is higher if the nodes have more residual energy. DEEC achieves a longer lifetime than the SEP and is also suitable for multi-level heterogeneous WSNs. However, the cluster selection is based on probability, and it makes the number of clusters not equal to expectancy.

This paper designs a balanced energy-efficient grouping (BEEG) protocol for multi-level heterogeneous WSNs. The proposed method is based on the SGCH that makes the number of clusters equal to expectancy. The method divides all nodes into several groups based on initial energy in place of the number of nodes. The proposed method extends network lifetime and fits the multi-level heterogeneous WSNs. This work compares the proposed method with LEACH, SEP and DEEC in simulations, showing that the proposed method prolongs the stability period (the time interval before the first node dies).

2. **The BEEG Protocol.**

This study divides the BEEG protocol into the grouping stage and the data transmission stage (see Figure 1). During the grouping stage, this work divides the nodes into several groups. Data transmission operation is broken up into rounds. Each round begins with a cluster setup phase followed by a steady-state phase. The clusters and cluster heads are formed in the cluster setup phase. The data are transmitted to the BS in the steady-state phase. The following summarizes the details of the BEEG protocol.

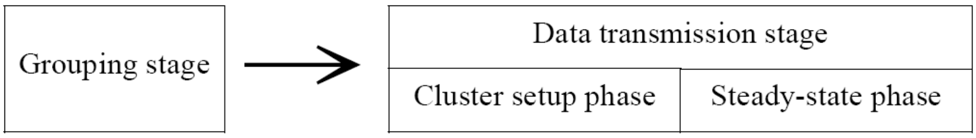


FIGURE 1. The stages of the BEEG protocol

2.1. **Grouping stage.**

The grouping stage assumes that the number of clusters is k, and the group number is set equal to the clusters number. The WSN contains m nodes and the nodes are denoted as $N_1, N_2, \ldots, N_m$. Figure 2 shows the process flow of the grouping stage. At the beginning, the BS broadcasts a group head request (GHR) message to all nodes. Each node sends back an acknowledgement (ACK) message when it receives the GHR. The ACK message includes the node's ID and initial energy information.

The BS computes the total energy while receiving all ACKs. The average energy of each group is the total energy divided by k. The BS selects a node with the latest reply to be the first group head (denoted as GH_1). In Figure 2, the N_m node is GH_1. The BS sends a group head (GH) message to GH_1. The GH message includes the group ID, number of groups (k) and the average energy of each group.

When a node receives the GH message with the group ID (i), it becomes a group head (denoted as GH_i) of the ith group. The GH_i has to find the group members. The GH_i broadcasts a group request (GR) message. The GR message includes the group ID and the group head ID. When the node receives a GR message, it sends an ACK message to GH_i if it does not belong to any group. The ACK message includes the node's ID and its initial energy.

On receiving the ACK message from each node, GH_i accumulates the initial energy of nodes in sequence according to the order of reception. When the sum of accumulated energy is equal to or bigger than the group average energy, the nodes with accumulated energy are set to be the group members and the node of next ACK reception is set to be the group head of the next group. The GH_i sends the group agreement (GA) message to the group member nodes. GH_i also adds 1 into i (the group ID) and sends a GH message to GH_i+1 (the node that is the group head of the next group).

When there is a node set to be GH_k (the N_n node in Figure 2), the nodes which do not belong to any group are members of the kth group. The GH_k node broadcasts the last group (LG) message. The LG message includes group ID and group head ID. When a node receives the LG message, it responds with an ACK message to GH_k if it does not belong to any group. The ACK message includes the node's ID and its initial energy. When the BS receives the LG message, it sends a message to all nodes for the start time of the data transmission stage.

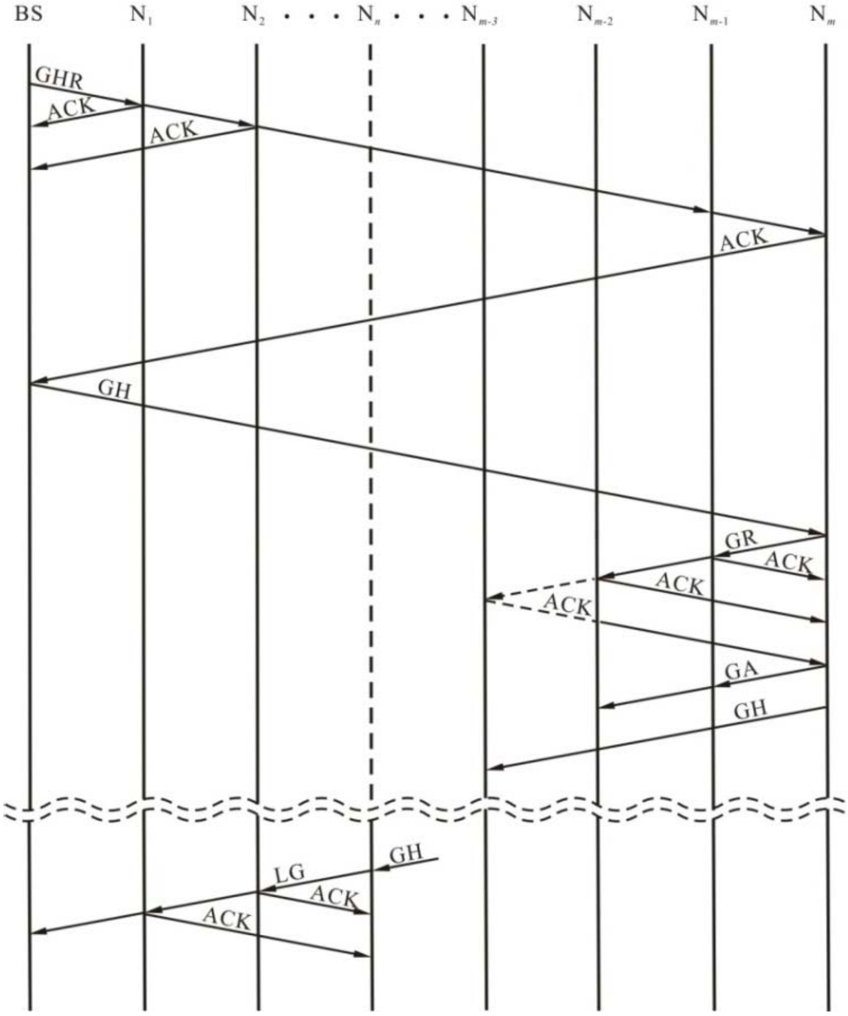


FIGURE 2. The process of the grouping stage

2.2. **Data transmission stage.** The main objective in the cluster setup phase is to select cluster heads and clusters. At the beginning, the node waits to broadcast a declaration (DEC) message (declaring it to be a cluster head). The waiting time is the reciprocal of the node's residual energy. The node with higher residual energy waits for a shorter time interval to broadcast the declaration. The DEC message includes its node ID and the group ID. The node will abort the DEC message if it receives a DEC message whose group ID is the same as its own. In a group, the node with maximum residual energy sends the DEC to become a cluster, while all other nodes abort their attempt to become the cluster head. In other words, a group elects a node with the maximum residual energy in the group to be the cluster head. After the node receives k DEC messages, it sends the join request (JR) message to the cluster head that receives the strongest signal strength.

In the steady-state phase, nodes send data to the cluster head during allocated time slots. The data contains node ID and the sensed information. Each cluster head aggregates received data and forwards it to the BS.

3. **Network Model.** This paper assumes 100 immobile sensor nodes, uniformly deployed in a 100m × 100m square region. Three kinds of sensor nodes include the high advanced node, middle advanced node and normal node with the initial energy of 2J, 1.5J and 0.5J, respectively. The BS is fixed and located (at the position of 50m, 175m). The node senses

at a fixed rate and always has data to transmit to the BS. The number of clusters (or the groups) is five [6].

This study also assumes a simple radio model as discussed in [13]. The transmitter consumes energy to run the radio electronics and the power amplifier. The receiver consumes energy to run the radio electronics. When the node transmits a message with l bits through a distance d, the node expends $E_{Tx}(l,d)$ energy and

$$E_{Tx}(l,d) = \begin{cases} lE_{elec} + l\varepsilon_{fs}d^2, & d < d_0 \\ lE_{elec} + l\varepsilon_{mp}d^4, & d \geq d_0 \end{cases} \tag{1}$$

When the node receives this message, it expends $E_{Rx}(l)$ energy and

$$E_{Rx}(l) = lE_{elec}, \tag{2}$$

where E_{elec} and $\varepsilon_{fs}d^2$ (or $\varepsilon_{mp}d^4$) are the electronics energy and the amplifier energy, respectively. Table 1 shows the energy parameters in this paper.

Table 1. Parameters of the radio model

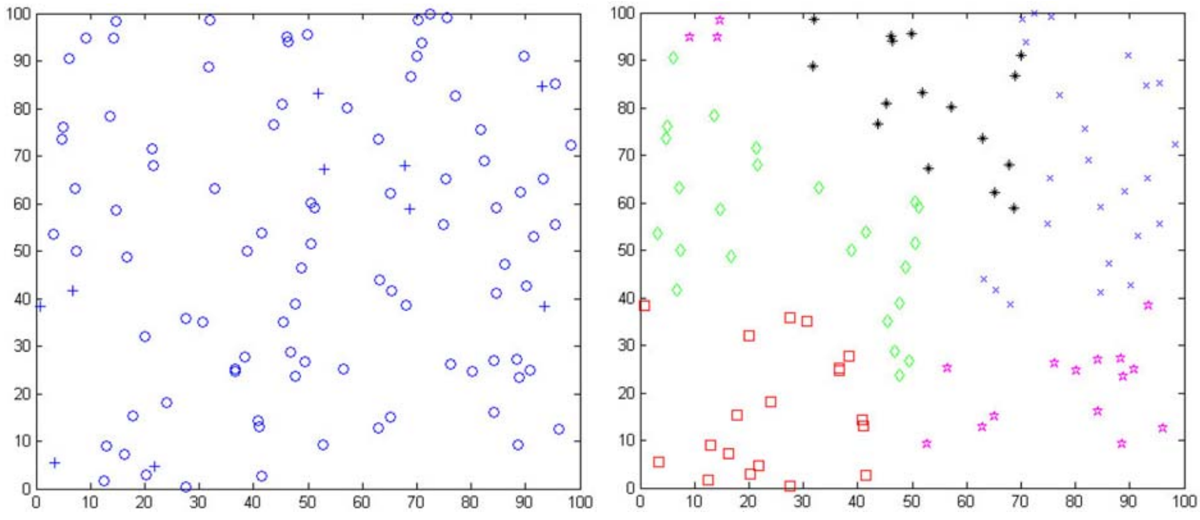
Parameter	Value
E_{elec}	50 nJ/bit
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/m^4
E_{DA}(for data aggregation)	5 nJ/bit/signal
Data size	4000 bits
Message size	100 bits

4. **Simulations Results.** The simulation uses MATLAB to evaluate performance of the BEEG, the DEEC, the SEP and the LEACH. Each method is simulated in two-level, three-level and multi-level heterogeneous WSNs. The following summarizes simulations and results.

In the two-level simulation, this work deploys ten high advance nodes and ninety normal nodes in the network. Ten network topologies are generated at random. Figure 3(a) shows a example of the network topologies, where the high advance node is denoted as a cross and the normal node is denoted as a circle. Figure 3(b) shows grouping result of Figure 3(a) by the BEEG. The current study applied the four methods to the ten generated networks. Figure 4 shows the results. Figure 4(a) shows the average number of nodes alive over simulation rounds. We can see that the stability time (the time interval before the first node dies) of the BEEG is the longest. Figure 4(b) shows the average number of messages received in the BS. The proposed method is obviously more efficient than the others.

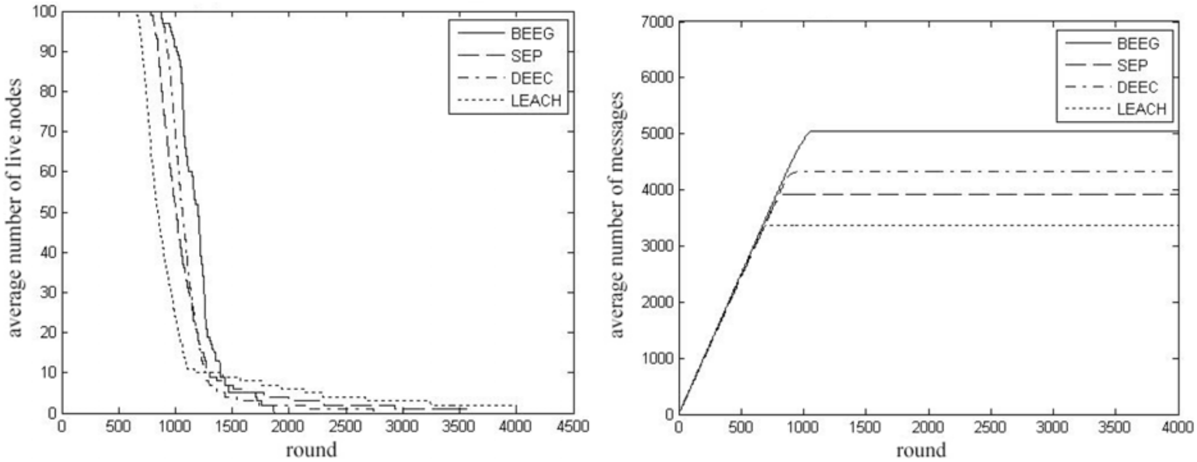
To show that the number of high energy nodes affects network lifetime, this work deploys $10, 20, 30, \ldots, 90$ high advance nodes with $90, 80, 70, \ldots, 10$ normal nodes, respectively. Figure 5 shows the average number of rounds when the first node dies. The DEEC stability period is longer than that of SEP and LEACH with the same results as in [22]. Findings also show that the BEEG obtains 29.8% more rounds than DEEC in the case of ninety high advanced nodes.

In the three-level simulation, we deploy thirty high advance nodes, thirty middle advance nodes and forty normal nodes in the network. We also generate ten topologies at random. Figure 6(a) shows a example of the network topologies, where the high advance node, the middle advance node and the normal node are denoted as a cross, a triangle and



(a) (b)

FIGURE 3. In two-level simulation: (a) a example of the topologies; (b) the grouping result by the BEEG



(a) (b)

FIGURE 4. The results of the two-level simulation: (a) the number of nodes alive over round and (b) the number of messages received in the BS

a circle, respectively. Figure 6(b) shows the BEEG grouping results. Figure 7 shows the results of four methods, demonstrating that the BEEG is better than the other methods.

To discover the node dying distribution over simulation rounds, this study records the rounds at the moment when the node died, showing the results in 3-D diagrams (see Figure 8). According to the results, the node dying distributions of LEACH and SEP are not uniform. This is because the LEACH does not discern energy discrepancy and the SEP is not suitable for three-level heterogeneous WSNs. In the DEEC and BEEG results, the node dying distributions are uniform. The BEEG obtains a better average node lifetime. The BEEG allocates energy efficiently and performs well in the three-level heterogeneous WSNs.

To show the simulation results of multi-level heterogeneous WSNs, the initial energy of nodes is randomly distributed in $[E_0, 4E_0]$, where E_0 is the initial energy of the normal

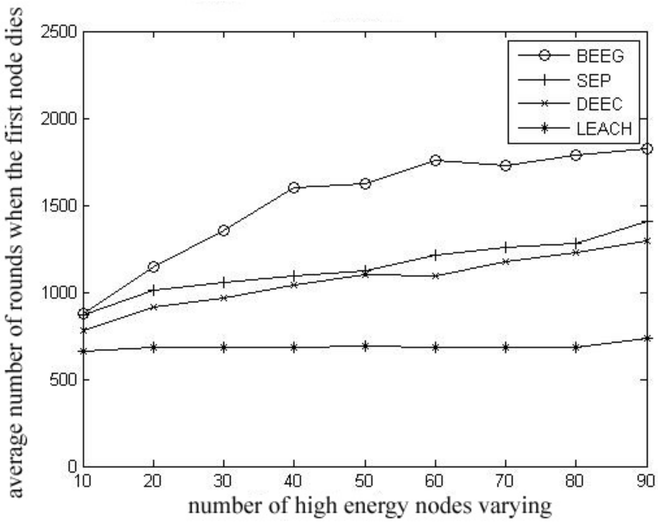


FIGURE 5. Average number of rounds of first node dies when the number of high energy nodes varies

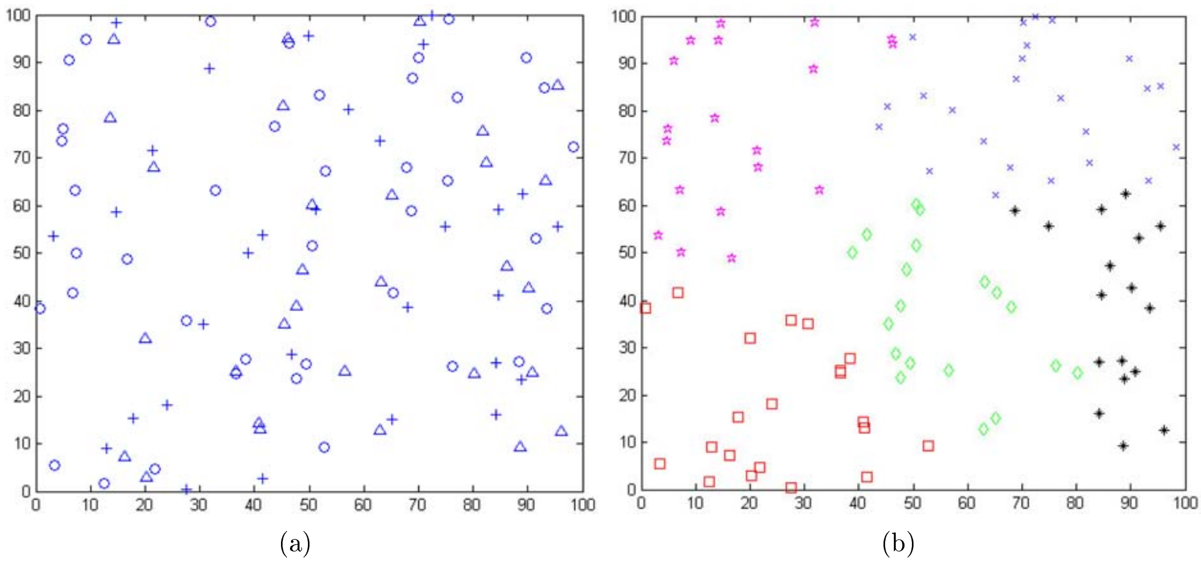
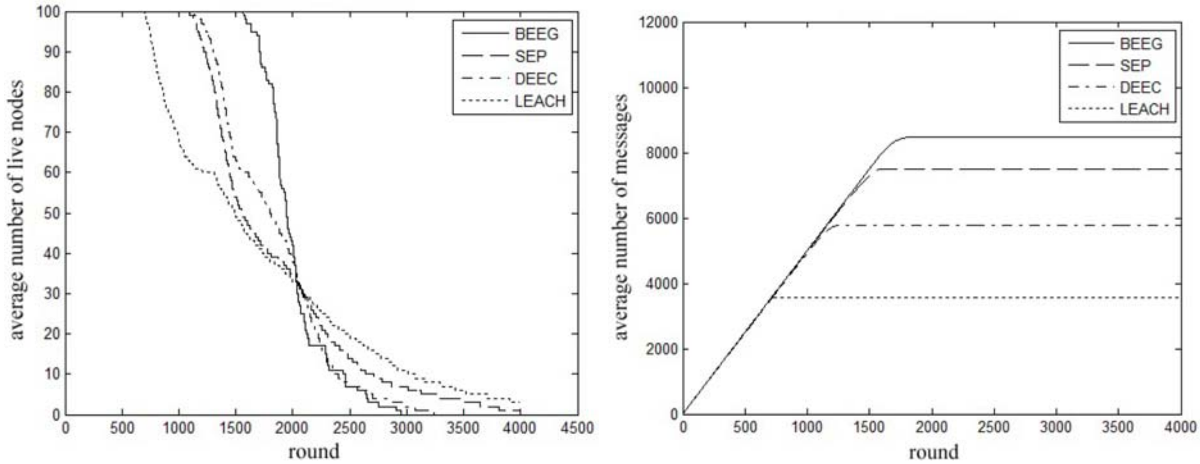


FIGURE 6. In three-level simulation: (a) the example topology of the network; (b) the grouping results by the BEEG

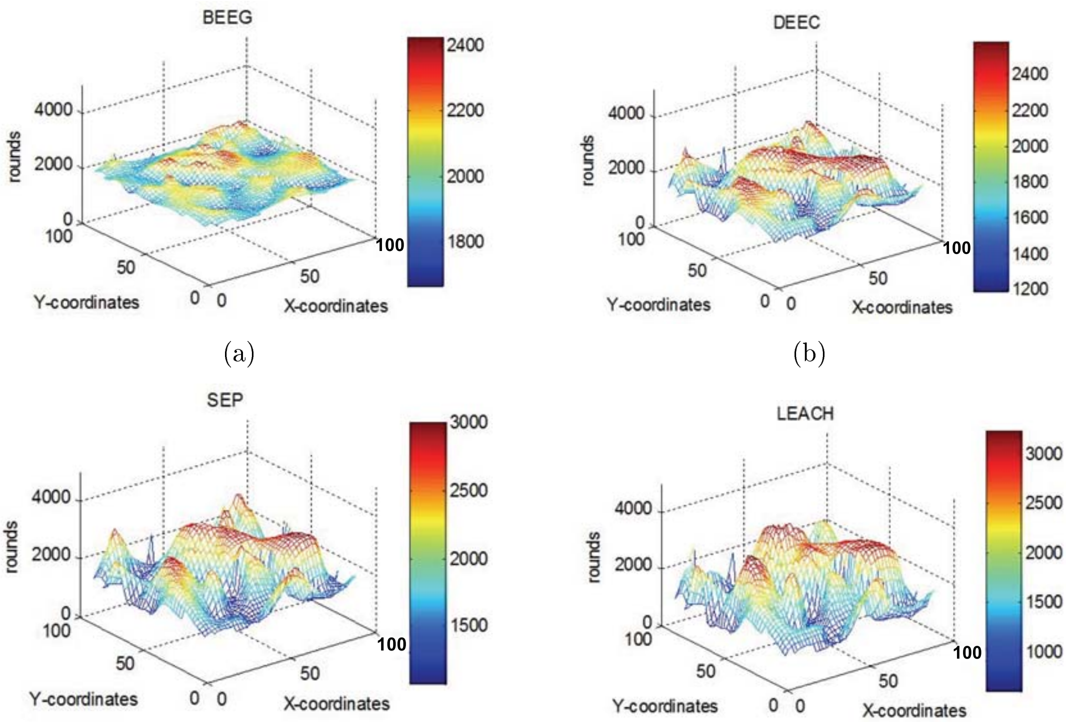
node. Figures 9(a) and 9(b) show the results of the number of nodes alive over rounds and the number of messages received in the BS. Figure 10 also shows the round where the node died. The average lifetimes (rounds) of nodes with LEACH, SEP, DEEC, and BEEG are 3015, 3119, 3176 and 3283, respectively. The performance of the proposed method is better than those of LEACH, SEP and DEEC.

According to the results of the average node dying distribution, even though the node dying distributions of BEEG is the best, we think the performance can be improved in the future work. For example, since the energy consumption is depended on the transmission distance, the distances between the groups to BS should be considered in the Grouping stage (compute the total energy of each group).



(a) (b)

FIGURE 7. The results of the three-level simulation, (a) the average number of nodes alive over round and (b) the average number of messages received in the BS



(a) (b) (c) (d)

FIGURE 8. The average node dying distribution of the three-level simulation: (a) BEEG, (b) DEEC, (c) SEP, and (d) LEACH

5. **Conclusions.** WSNs are increasingly useful and have been widely applied in many critical applications. Since the sensor nodes are constrained by limited energy, one of the most important issues in the WSNs is to reduce energy consumption. The LEACH is a popular protocol for reducing energy consumption and is designed for homogeneous

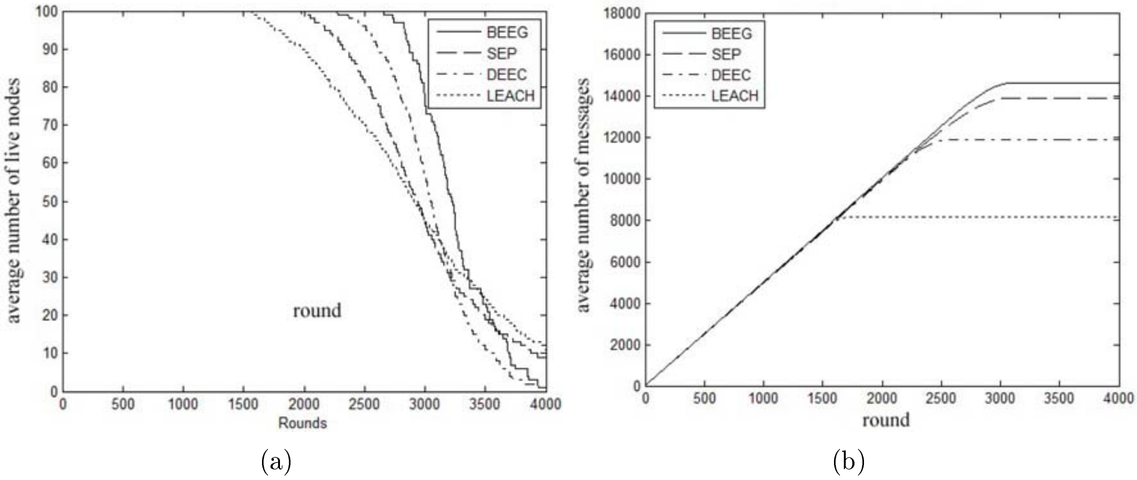


FIGURE 9. The results of the multi-level simulation: (a) the average number of nodes alive over round and (b) the average number of messages received in the BS

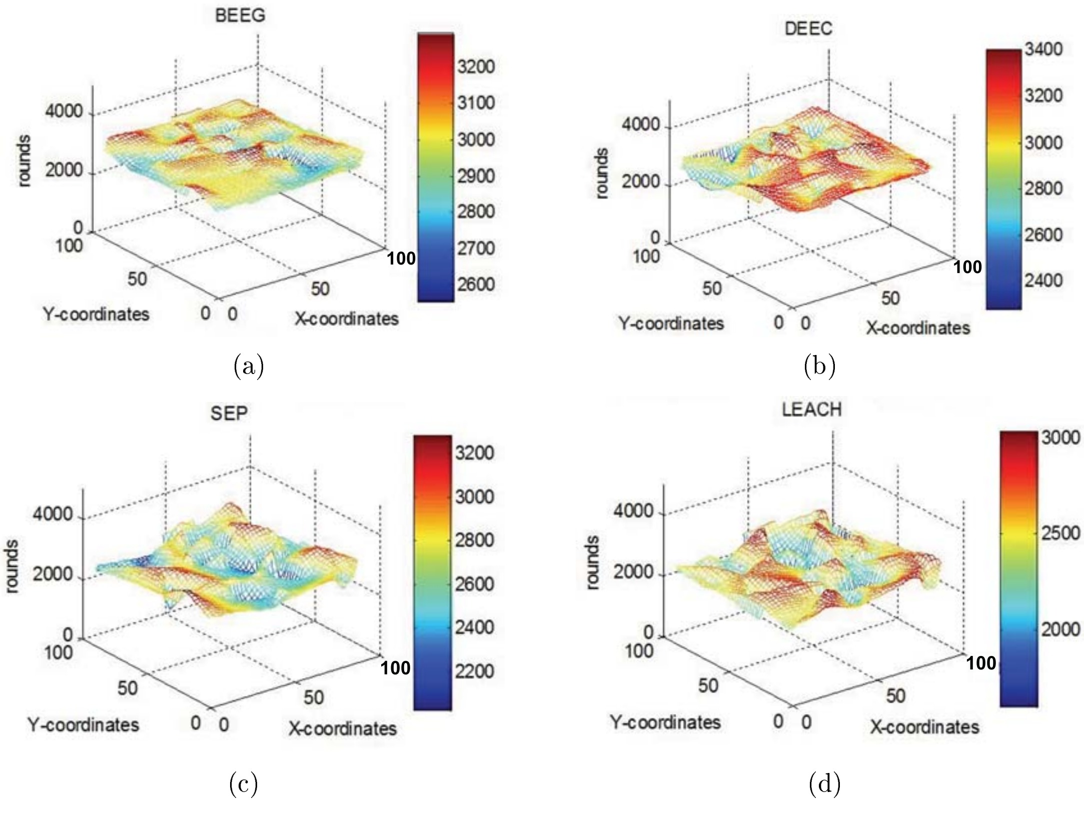


FIGURE 10. The average node dying distribution of the multi-level simulation: (a) BEEG, (b) DEEC, (c) SEP, and (d) LEACH

WSNs. This paper proposes the BEEG for multi-level heterogeneous WSNs. The proposed method is based on the SGCH that makes the number of clusters equal to expectancy. All nodes are divided into several groups based on the initial energy that extends lifetime and fits for the multi-level heterogeneous WSNs. We compare the BEEG with the LEACH, the SEP and the DEEC in simulations. This study also uses two-level, three-level and multi-level WSNs to show that the BEEG prolongs stability time. Performance of the BEEG is better than that of LEACH, SEP and DEEC. In the future work, we will consider the transmission distance (the distances between the groups to BS) to improve the performance.

Acknowledgment. This work was supported by National Science Council, Taiwan (NSC 99-2221-E-324-043 and NSC 100-2221-E-324-011).

REFERENCES

[1] C.-Y. Chen, H.-C. Chao, S.-Y. Kuo and K.-D. Chang, Rule-based intrusion detection mechanism for IP multimedia subsystem, *Journal of Internet Technology*, vol.9, no.5, pp.329-336, 2008.

[2] W.-E. Chen, Y.-B. Lin and R.-H. Liou, A weakly consistent scheme for IMS presence service, *IEEE Trans. on Wireless Communications*, vol.8, no.7, pp.3815-3821, 2009.

[3] C.-T. Li, M.-S. Hwang and Y.-P. Chu, An efficient sensor-to-sensor authenticated path-key establishment scheme for secure communications in wireless sensor networks, *International Journal of Innovative Computing, Information and Control*, vol.5, no.8, pp.2107-2124, 2009.

[4] C.-L. Wang, T.-P. Hong, G. Horng and W.-H. Wang, A GA-based key-management scheme in hierarchical wireless sensor networks, *International Journal of Innovative Computing, Information and Control*, vol.5, no.12(A), pp.4693-4702, 2009.

[5] S. Liang, Y. Tang and Q. Zhu, Passive wake-up scheme for wireless sensor networks, *ICIC Express Letters*, vol.2, no.2, pp.149-154, 2008.

[6] M. Yoshimura, H. Nakano, A. Utani, A. Miyauchi and H. Yamamoto, An effective allocation scheme for sink nodes in wireless sensor networks using suppression PSO, *ICIC Express Letters*, vol.3, no.3(A), pp.519-524, 2009.

[7] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, Wireless sensor networks: A survey, *Computer Networks*, vol.38, no.3, pp.393-422, 2002.

[8] R. P. Mann, K. R. Namuduri and R. Pendse, Energy-aware routing protocol for ad hoc wireless sensor networks, *EURASIP Journal on Wireless Communications and Networking*, vol.5, pp.635-644, 2005.

[9] S. Tilak, N. B. Abu-Ghazaleh and W. Heinzelman, A toxonomy of wireless microsensor network models, *ACM Mobile Computing and Communications Review*, vol.6, no.2, pp.28-36, 2002.

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

[11] P. Kirshna, N. H. Vaidya, M. Chatterjee and D. K. Pradhan, A cluster-based approach for routing in dynamic network, *ACM SIGCOMM Computer Communication Review*, vol.27, no.2, pp.49-64, 1997.

[12] S.-F. Hwang, Y.-Y. Su, K.-H. Lu, Y.-Y. Lin and C.-R. Dow, A cluster-based coverage-preserved scheduling scheme in wireless sensor networks, *Journal of Internet Technology*, vol.10, no.1, pp.43-50, 2009.

[13] C. R. Lin and M. Gerla, Adaptive clustering for mobile wireless networks, *IEEE Journal on Selected Areas in Communications*, vol.15, no.7, pp.1265-1275, 1997.

[14] A. B. McDonald and T. F. Znati, Design and performance of a distributed dynamic clustering algorithm for ad-hoc networks, *Proc. of the 34th IEEE Computer Society on Annual Simulation Symposium*, Seattle, USA, pp.27-23, 2001.

[15] O. Younis and S. Fahmy, HEED: A hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks, *IEEE Trans. on Mobile Computing*, vol.3, no.4, pp.366-379, 2004.

[16] C.-Y. Wen and W. A. Sethares, Automatic decentralized clustering for wireless sensor networks, *EURAIP Journal on Wireless Communications and Networking*, vol.5, pp.686-697, 2005.

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

[18] S. Lindsey and C. S. Raghavenda, PEGASIS: Power efficient gathering in sensor information systems, *Proc. of IEEE Aerospace Conference*, Montana, USA, pp.3-1125-3-1130, 2002.

[19] Y. J. Wang and J. J. Liaw, The group clustering algorithm for LEACH, *Proc. of National Symposium on System Science and Engineering Conference*, I-Lan, Taiwan, 2008.

[20] X. Du and F. Lin, Improving routing in sensor networks with heterogeneous sensor nodes, *Proc. of the 61st IEEE Vehicular Technology Conference*, Stockholm, Sweden, pp.2528-2532, 2005.

[21] L. Ying and Y. Haibin, Energy adaptive cluster-head selection for wireless sensor networks, *Proc. of the 6th International Conference on Parallel and Distributed Computing, Applications and Technologies*, Dalian, China, pp.1-5, 2005.
[22] M. Rajiullah and S. Shimamoto, An energy-aware periodical data gathering protocol using deterministic clustering in wireless sensor networks (WSN), *Proc. of Wireless Communications and Networking Conference*, Hong Kong, pp.3014-3018, 2007.
[23] S. Lindsey, C. Raghavendra, K. M. Sivalingam, Data gathering algorithms in sensor networks using energy metrics, *IEEE Transactions on Parallel and Distributed Systems*, vol.13, no.9, pp.924-935, 2002.
[24] S. Bandyopahyay, E. J. Coyle, An energy efficient hierarchical clustering algorithm for wireless sensor networks, *Proc. of the 22nd Annual Joint Conference of the IEEE Computer and Communications Societies*, San Francisco, USA, pp.1713-1723, 2003.
[25] G. Smaragdakis, I. Matta and A. Bestavros, SEP: A stable election protocol for clustered heterogeneous wireless sensor networks, *Proc. of the 2nd International Workshop on Sensor and Actor Network Protocol and Applications*, Boston, USA, pp.1-11, 2004.
[26] L. Qing, Q. Zhu and M. Wang, Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks, *Computer Communications*, vol.29, pp.2230-2237, 2006.