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Wireless Meter Reading Based Energy-Balanced Steady Clustering Routing Algorithm for Sensor Networks

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***Abstract*—According to the characteristics of wireless meter reading system, an energy-balanced and energy-efficient steady clustering routing algorithm (EBSC, Energy-Balanced Steady Clustering) is proposed. In the clustering mechanism, the current cluster head nodes determine cluster head nodes for next round according to the residual energy of the cluster members. In the next round, each non-cluster head node decides the cluster to which it will belong according to energy-distance function. The cluster head nodes send data to base station by the communication model of single hop and multi-hop that is decided according to the criterion of minimum energy consumption. In EBSC algorithm, the number of cluster head nodes generated in each round is very steady, and EBSC combines the advantage both distributed and centralized clustering algorithm. Experimental results show that the proposed routing algorithm not only efficiently uses limited energy of network nodes, but also well balances energy consumption of all nodes, and significantly prolongs network lifetime.**

***Index Terms*—Energy-balanced, Energy-distance function, Steady clustering, Wireless sensor networks**

I. Introduction

In recent years, sensor networks have attracted much interest in wireless research community as a fundamentally new tool for a wide range of monitoring and data-gathering applications. One of their important applications is wireless remote meter reading, with the feature of wide area monitoring points and equipment scattered layout. Wireless remote meter reading system is used to measure the consumption of electricity, gas, water, heat, liquid, oil and steam, since the direct physical access or visual reading of meters are very inconvenient. These sensor networks usually comprise small, low-power devices that integrate sensors and actuators with limited on-board processing and wireless communication capabilities.

Wireless sensor networks (WSNs) are a class of wireless ad hoc networks in which sensor nodes collect, process, and communicate data acquired from the physical environment to an external base station (BS), hence allowing for monitoring and control of various physical parameters [1]. BS with unlimited energy is responsible for receiving, processing data from sensor nodes. Sensor nodes in such data-gathering sensor networks are generally powered by small inexpensive batteries in expectation of surviving for a long period. Therefore, energy is of utmost importance in power-constrained data-gathering sensor networks, and energy consumption should be well managed to maximize the post-deployment network lifetime.

Clustering is a good manage manner of WSNs. The set of sensor nodes in such algorithms is divided into several subsets according to some rules, and each subset becomes a cluster with a cluster head node. Cluster head nodes are responsible for global routing, and for managing the cluster member nodes, and for coordinating the work among the member nodes, and for collecting intra-cluster information, and for data aggregation [2], and for inter-cluster forwarding. Cluster member nodes receive or send data through cluster head nodes.

Clustering algorithms belong to either one of two categories: distributed and centralized [3]. The centralized approach assumes that the existence of a particular node is cognizant of the information pertaining to the other network nodes. Then, the problem is modeled as a graph partitioning problem with particular constraints that render this problem NP-hard. The central node determines clusters by solving this partitioning problem. However, the major drawbacks of this category are linked to additional costs engendered by communicating the network node information and the time required to solve an optimization problem. Heinzelman et al. [4] propose a centralized version of Low Energy Adaptive Clustering Hierarchy (LEACH), in order to produce better clusters by dispersing cluster head nodes throughout the network. In this protocol, each node sends information regarding its current location and energy level to the BS node, which computes the node’s mean energy level, and nodes, whose energy level is inferior to this average, cannot become cluster head nodes for the current round. Considering the remaining nodes as possible cluster head nodes, BS node finds clusters using the simulated annealing algorithm [5] in order to find optimal clusters. In the second category, the distributed method, each node executes a distributed clustering algorithm. Distributed algorithms include two categories: one is that sensor node decides for whether electing itself as cluster head node such as LEACH algorithm [6], and the other is that cluster head node is dynamically selected through the information exchange

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between nodes such as hybrid energy-efficient distributed clustering (HEED) algorithm [7] and HEED-M algorithm [8]. LEACH, one of the most frequently referenced methods, is the first proposed and typical distributed clustering algorithm for WSNs. LEACH utilizes randomized rotation of local cluster head nodes to evenly distribute the energy load among the sensors in the network and uses localized coordination to enable scalability and robustness for dynamic networks, and incorporates data fusion into the routing protocol to reduce the amount of information that must be transmitted to BS. HEED algorithm periodically selects cluster head nodes according to a hybrid of the node residual energy and a secondary parameter, such as node proximity to its neighbors or node degree. HEED terminates in O(1) iterations, incurs low message overhead, and achieves fairly uniform cluster head node distribution across the network. Due to this repetitive information iteration, communication overhead of the algorithm significantly increase. The only difference between HEED and HEED-M algorithm is that the former uses single-hop communication mode and the latter uses multi-hop communication mode when cluster head nodes transmit data to BS. The major drawback of distributed method is that nodes have limited knowledge pertaining to their neighborhood. Hence, clusters are not built in an optimal manner.

Recently, many clustering algorithms for WSNs have been reported as an effort to prolong the network lifetime in the literature [9]–[16]. Clustering schemes EEUC [9] was proposed to balance energy consumption among cluster head nodes. In the algorithm, the number of cluster members near BS was reduced by partitioning the network into clusters with unequal size. In [10], the approach for computing the optimal number of coronas in terms of maximizing network lifetime is presented. Based on the mathematical model, an energy-balanced data gathering (EBDG) protocol is designed and the solution for extending EBDG to large-scale data-gathering sensor networks is also presented. Kaur et al. [11] proposed a new cluster-based approach to increase the overall network lifetime of WSNs by designing the network with multiple-sized fixed grids while taking into account the arbitrary-shaped area sensed by the sensor nodes. In [12], the authors investigated the problems of avoiding energy holes and maximizing lifetime in sensor networks with uniform distribution and uniform reporting based on corona-based network division and power-adjusted transmission. Jarry et al. [13] used the probabilistic data propagation algorithm in [14] and proved that there is a relationship between energy balancing and life-span maximization. However, the above schemes did not give the solution for balancing energy consumption among nodes in the same slice and the solution for maximizing network lifetime. In [15], the authors gave a formal definition of an optimal data propagation algorithm with the objective to maximize network lifetime, and employed a spreading technique to balance energy consumption among sensors within the same slice. In [16], the problem of balancing energy consumption on a linear data-gathering sensor network by considering energy consumption for both data transmission and data receiving was studied.

In this paper, we investigate the most important problems, balancing energy consumption and maximizing network lifetime, for designing routing algorithm of wireless meter reading system based on WSNs, and propose an energy-balanced steady clustering algorithm called EBSC. In the clustering mechanism, the current cluster head nodes determine cluster head nodes for next round according to the residual energy of the cluster members. In the next round, each non-cluster-head node decides the cluster to which it will belong according to energy-distance function. The cluster head nodes sent data to BS by the communication model of single hop and multi-hop in order to reduce energy consumption. In EBSC algorithm, the number of cluster head nodes generated in each round is very steady, and the residual energy of cluster head nodes is the largest among the cluster members, and the communication cost for inter-cluster and intra-cluster is very small. EBSC algorithm combines the advantage both distributed and centralized clustering algorithm, and overcomes the shortcoming of two types of algorithms. Experimental results show that the proposed routing algorithm not only efficiently uses of limited energy of network nodes, but also well balances energy consumption of all nodes, and significantly prolongs network lifetime.

The remainder of this paper is organized as follows: Section II gives the network model. Section III describes EBSC algorithm, and Section IV analyzes EBSC algorithm. In Section V, EBSC is evaluated through extensive simulations by comparing with several popular routing protocols. Finally, this paper is concluded in Section VI.

II. NETWORK MODEL

Assume a set of sensors is dispersed on a rectangular field. The nodes send data to the respective cluster head nodes, which in turn compresses the aggregated data and transmits it to BS. We assume the following properties about the network:

1) BS is located far from the sensor nodes and is immobile.

2) Sensor nodes have no mobility after deployed.

3) BS saves the location information of all nodes.

4) All nodes in the network are homogeneous and energy constrained.

5) According to receiver distance, sensor nodes can adjust transmission power to save energy consumption.

6) The propagation channel is symmetric and sensor nodes can calculate the approximate distance from the sender, according to received signal strength.

The network model we have used is similar to the literature [4]. The transmitter dissipates energy to run the radio electronics and the power amplifier. The receiver dissipates energy to run the radio electronics. When a node transmits a message with l bits through distance d , the node expends $E_{Tx}(l,d)$ energy and

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

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

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

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where E_{elec} is the energy dissipated per bit to run the transmitter or the receiver circuit, whereas the amplifier energy coefficient, ε_{fs} and ε_{mp}, depend on the transmitter amplifier model, and d is the distance between sender and receiver. By equating the two expressions at $d = d_0$, we have $d_0 = \sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$. For the experiments described in this paper, the communication energy parameters are set as $E_{elec} = 50$ nJ/bit, $\varepsilon_{fs} = 10$ pJ/bit/m2, and $\varepsilon_{mp} =$ 0.0013pJ/bit/m4. Using the results in the literature [4], the energy for data aggregation is set as $E_{DA} = 5$ nJ/bit/signal.

III. EBSC ALGORITHM

The operation of EBSC is divided into rounds as with LEACH, but the phases of each round are different. EBSC algorithm consists of four phases: (1) A set-up phase when clusters are organized; (2) A phase in which cluster head nodes for next round are selected; (3) A steady-state phase when data are transferred from nodes to BS; (4) A phase in which BS broadcasts the message about cluster head nodes for next round to all nodes.

Because this algorithm is based on wireless meter reading system, BS will have their location information after sensor nodes are deployed. Initially, cluster head nodes for the first round need to be selected by BS. To find the optimum number of clusters and elect cluster head nodes the density of which is uniform throughout cluster area, the whole sensor region is divided into several squares by BS according to the parameter *step*, and the sensor nodes closest to the midpoint of squares become cluster head nodes for the first round. Then, BS sends the message about cluster head nodes to the elected nodes.

After electing cluster head nodes for the first round, the algorithm begins with following circulation:

1) Each cluster head node broadcasts an advertisement message using a nonpersistent carrier-sense multiple access (CSMA) MAC protocol. Each non-cluster head node determines its cluster for this round by choosing the cluster head node that requires the minimum communication energy, according to energy-distance function based on received signal strength of the advertisement from each cluster head node, and then it must transmit a message back to the cluster head node that it will be a member of the cluster.

2) Each cluster head node elects the cluster member node with the largest residual energy to be the cluster head node for next round.

3) Each cluster member node sends its data to the cluster head node during its allocated TDMA transmission slot. Once the cluster head node receives all the data, it performs data aggregation to enhance the common signals and reduce the uncorrelated noise among the signals, and broadcasts its information to other cluster head nodes. Then, the cluster head node sends the resultant data to BS by the communication model of single hop and multi-hop that is decided according to the criterion of minimum energy consumption in order to reduce energy consumption.

4) BS sends the message about cluster head nodes to the elected nodes for next round.

A. Cluster Set-Up Phase

When a new round begins, each cluster head node broadcasts an advertisement message HEAD_MSG consisting of its ID and current residual energy. After receiving the message, each non-cluster head node decides to which cluster it belongs according to energy-distance function that is given by

$$f(i,j) = \frac{d^2(j, CH_i)}{RE_i} \tag{3}$$

where i is ID of cluster head node, j is ID of non-cluster head node, $d(j, CH_i)$ is the distance from the node j to the cluster head node i, and RE_i is the residual energy of cluster head node i. The non-cluster head node s_j will belong to the cluster s_i that makes energy-distance function $f(i,j)$ minimum, and that is

$$\arg\min_{1\le i\le CH}\{f(i,j)\}. \tag{4}$$

where CH is the number of cluster head nodes. Energy-distance function not only introduces distance information, but also energy factor. Thus, it can effectively balance the current energy consumption of cluster head nodes. The reason is

$$\arg\min_{1\le i\le CH}\{f(i,j)\} = \arg\min_{1\le i\le CH}\{\frac{d^2(j, CH_i)}{RE_i}\}$$
$$= \arg\min_{1\le i\le CH}\{\frac{l\cdot\varepsilon_{fs}\cdot d^2(j, CH_i)}{l\cdot\varepsilon_{fs}\cdot RE_i}\}. \tag{5}$$

where $l\cdot\varepsilon_{fs}\cdot d^2(j, CH_i)$ is the part of dynamic energy dissipated in transmitting data to cluster head node i for node j. From formula (5), it is easy to observe that the smaller $l\cdot\varepsilon_{fs}\cdot d^2(j, CH_i)$ is, the smaller $f(i,j)$ is, and the larger RE_i is, the smaller $f(i,j)$ is.

After each node has decided to which cluster it belongs, it must inform the cluster head node that it will be a member of the cluster. Each node transmits a JOIN_MSG message containing its ID and residual energy after the round to its cluster head node. The residual energy is

$$RE_j = RE - E1 - E2 \tag{6}$$

where RE indicates the current residual energy of the node, $E1$ and $E2$ represent the energy dissipated in transmitting JOIN_MSG message and data to its cluster head node, respectively.

The cluster head nodes act as local control centers to coordinate data transmissions in EBSC. They set up a TDMA schedule and transmit it to each node in the cluster. This ensures that there are no collisions among data messages and also allows the radio component of each non-cluster head node to be turned off at all times except during their transmitting time, thus reducing the energy consumed by sensors. After TDMA schedule is known by all nodes in the cluster, set-up phase is completed.

B. Cluster Head Node Selection Phase for Next Round

To balance the energy of the network, cluster head node must have much more energy than non-cluster head node. Thus, cluster head node elects the cluster member nodes with the largest residual energy to be the cluster head node

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for next round.

C. Data Transmission Phase

After all nodes know the TDMA schedule in the cluster, they transmit data to their cluster head node during their allocated TDMA slot. When the cluster head node receives all the data, it performs data aggregation, and broadcasts a message NODE_MSG consisting of its ID, the current residual energy and the distance from itself to BS. Then the cluster head node transmits the resultant data to BS by the communication model of single hop and multi-hop, because the communication model that is only set as single hop or multi-hop will lead to imbalance energy consumption of cluster head nodes. We assume that data redundancy is limited, and the data of different cluster head nodes can not be aggregated, and relaying cluster head nodes only forward the data from other cluster head nodes.

The cluster head node limits the selection range of its candidates that are nearer to BS than itself. Thus, the set of its candidates needs to be established, and is defined as follows:

$$s_{i-RCH} = \left\{ s_j \mid d(s_j, BS) < d(s_i, BS) \right\} \quad (7)$$

where s_{i-RCH} represents the set of cluster head node s_i, $d(s_i, BS)$ and $d(s_j, BS)$ are the distance from the node s_i and its candidate s_j to BS, respectively.

The cluster head node s_i selects a node s_j as relaying node from the set s_{i-RCH}, and selection strategy is analyzed as follows: We assume that s_j directly transmits the data to BS after received them from s_i. Therefore, to transmit l bits to BS, the total energy for s_i and s_j is

$$\begin{aligned} E_{2hop-E} &= E_{Tx}(l, d(s_i, s_j)) + E_{Rx}(l) + E_{Tx}(l, d(s_j, BS)) \\ &= 3lE_{elec} + lE_{Tx-amp}(d(s_i, s_j)) + lE_{Tx-amp}(d(s_j, BS)) \end{aligned} \quad (8)$$

where

$$E_{Tx-amp}(d) = \begin{cases} \varepsilon_{fs} d^2 & d < d_0 \\ \varepsilon_{mp} d^4 & d \ge d_0 \end{cases}. \quad (9)$$

When cluster head node s_i directly transmits the data to BS, the dissipated energy is

$$E_{1hop-E} = E_{Tx}(l, d(s_i, BS)) = lE_{elec} + lE_{Tx-amp}(d(s_i, BS)). \quad (10)$$

Thus, if there is only one node s_j in the set s_{i-RCH} to satisfy $E_{2hop-E} < E_{1hop-E}$, s_j will be selected as the relaying node for s_i, and if there are many nodes to do that, the node whose residual energy is the largest will be selected, and if none of them satisfy the formula, s_i will directly transmit data to BS.

IV. Analysis of Basic Algorithm

In EBSC algorithm, we use the approach of centralized clustering algorithm to solve the problems that the number of cluster head nodes generated in each round is not steady and the residual energy of cluster head nodes is very difficult to judge in distributed clustering algorithm, and we use the approach of distributed clustering algorithm to overcome the shortcomings that the additional energy is dissipated for transmitting information between node and BS in centralized clustering algorithm. In addition, in the phase that cluster head nodes send data to BS, we design the communication model of single hop and multi-hop and propose the criterion of minimum energy consumption in order to reduce energy consumption. The detailed algorithm is given as follows:

Algorithm: EBSC

For $i = 1:1: NodeNumber$
  Locate s_i at $square_j$;
  If $\min(s_i, midpoint_j)$ then
    $beClusterHead \leftarrow true$;
  End if
End for
For $r = 1:1: MaxRound$
  Broadcast $HEAD\_MSG(ID, RE)$;
  For $j = 1:1: NodeNumber$
    Calculate $f(i, j)$;
    Select $ClusterHead$ with $\min f(i, j)$;
    Calculate RE_j;
    Send $JOIN\_MSG(ID, RE_j)$ to s_i;
    Translate data to $ClusterHead$;
  End for
  For $i = 1:1: ClusterHeadNumber$
    Select the s_j with $\max RE_j$;
    Aggregate data;
    Broadcast $NODE\_MSG(ID, RE_i, D_{i-BS})$;
  End for
  For $i = 1:1: ClusterHeadNumber$
    If $d(s_k, BS) < d(s_i, BS)$ then
      Add s_k to s_{i-RCH};
    End if
    Calculate E_{2hop-E} and E_{1hop-E};
    If $\forall s_k \in s_{i-RCH}$, $E_{2hop-E} < E_{1hop-E}$ then
      Select the s_k with $\max RE_k$;
      Translate data to BS through s_k;
    Else
      Translate data to BS;
    End if
  End for
  BS Broadcast the next $ClusterHead$;
End for

In this algorithm, the broadcast radius of cluster head node is set as the maximum distance from itself to the four vertices of network coverage when broadcasting HEAD_MSG and NODE_MSG messages, and the broadcast radius of non-cluster head node is the distance from itself to its cluster head node when broadcasting JOIN_MSG message. We need to analyze the message complexity in order to research the energy efficiency.

Property: *The message complexity of EBSC algorithm is* $O(N)$, *where* N *is the total amount of sensor nodes in the*

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whole network.

Proof: Let n be the number of cluster head nodes for a round in networks. Thus, in the whole round, the total amount of HEAD_MSG and NODE_MSG messages broadcasted by cluster head nodes is n, respectively, and the total amount of JOIN_MSG messages sent by non-cluster head nodes is $N-n$. Obviously, the total amount of messages is $n+n+N-n=N+n$, and the message complexity of EBSC algorithm is $O(N)$. Therefore, the property is proven.

By the property, it can be observed that the message consumption of EBSC algorithm is very small, and that the energy efficiency is very high. The message complexity is also $O(N)$ in EEUC algorithm [9] and DEEUC algorithm proposed by the literature [17], and is less than that in HEED algorithm [7]. The message consumption of EBSC is small compared with that of EEUC and DEEUC. Therefore, the energy efficiency of EBSC is higher than that of EEUC and DEEUC.

V. Simulation Results and Analysis

The performance of the proposed approach was evaluated by computer simulations and the results are given in this section. To demonstrate the efficiency of EBSC algorithm via balancing energy consumption and maximizing network lifetime, we compared our scheme with three other schemes, LEACH scheme, HEED scheme, and HEED-M scheme. The parameters used in the experiment are shown in Table I.

TABLE I. SIMULATION PARAMETERS

Parameter	Value	Unit
Network Area	(0,0)~(200,200)	m
BS Location	(100,250)	m
Number of Nodes	400	
Data Message	4000	bits
Initial energy	0.5	J

A. Analysis of the Selection of Parameter step

It is very important to analyze the selection of the parameter *step* that decides the number of cluster head nodes in EBSC algorithm. We use experiment to select the *step* value. Let *step* change from 20 to 100, then we observe of the change of the time ranging from the first dead node to the final dead node in the networks. We run 10 times of experiments for each *step* value, and the corresponding average results are shown in Fig.1. Fig.1 shows that the time of the first dead node is the longest when $step=50$, and the time of the final dead node is the longest when $step=90$. When $step=50$, the time span from the first dead node to the final dead node is the shortest, which can reflect the balance of energy in the networks. From the above analysis, we can draw a conclusion that the shorter the time span is, the more balanced the energy is. Therefore, when the parameter $step=50$, the network lifetime is longer and the energy consumption is more balanced.

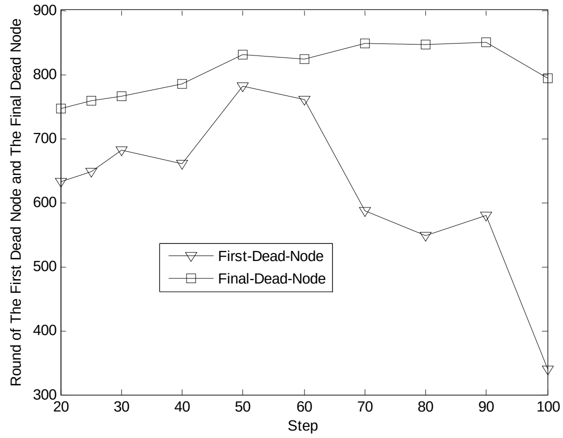

Figure 1. The change of the time ranging from the first dead node to the final dead node in the networks with different *step* values

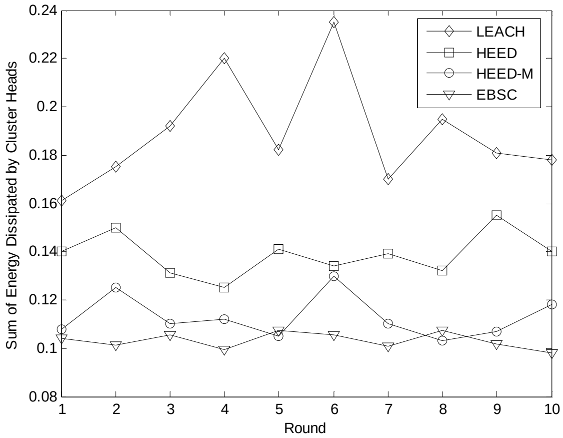

Figure 2. The sum of energy dissipated by cluster head nodes in four algorithms

B. The Energy Consumption of Cluster Head Node

As a cluster head node is much more energy intensive than being a non-cluster head node, we research the sum of energy dissipated by cluster head nodes during a round. In our experiments, we randomly select the data during ten rounds, as shown in Fig.2. Fig.2 shows that the energy dissipated by cluster head nodes in EBSC is the lowest and has the minimum fluctuation among all of the algorithms. The reasons are the message consumption in EBSC is very slight. The cluster head nodes send data to BS by the communication model of single hop and multi-hop, so the energy consumption is significantly reduced. In addition, the amount of cluster head nodes in EBSC is steady before the nodes begin to die, and thus, there isn't an obvious fluctuation in the sum of energy dissipated by cluster head nodes. The energy dissipated by cluster head nodes in LEACH algorithm is the highest and has the maximum fluctuation among all of the algorithms. The reasons are the cluster head nodes send data to BS by the communication model of single hop in LEACH and the amount of cluster head nodes elected in LEACH is very large, and as a result, the energy consumption is increased. In addition, the unstable property of the amount of cluster head nodes in LEACH leads to the obvious fluctuation of the sum of energy dissipated by cluster head nodes. The HEED and HEED-M are between EBSC and LEACH for the sum of energy dissipated by cluster head nodes and its fluctuation, and the sum of energy dissipated by cluster head nodes in

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HEED-M is lower than that in HEED, because the communication model of multi-hop is used in HEED-M.

C. The Lifetime of Networks

The problem of maximizing network lifetime by balancing energy consumption among all nodes in the network is the most important one that needs to be solved in the design of the routing algorithm of WSNs. Fig.3 illustrates the number of live nodes in the networks during the variation of the number of rounds for EBSC, LEACH, HEED and HEED-M algorithm. The number of live nodes can reflect the energy efficiency in the networks, and the more the number of live nodes is, the higher the energy efficiency is. From Fig.3, it is easy to observe that the lifetime of EBSC is the longest and the time span of EBSC from the first dead node to the final dead node is also the shortest among all of the algorithms. From the above analysis, it shows that EBSC can not only efficiently employ the limited energy of nodes, but also well balance the energy consumption of all nodes in WSNs.

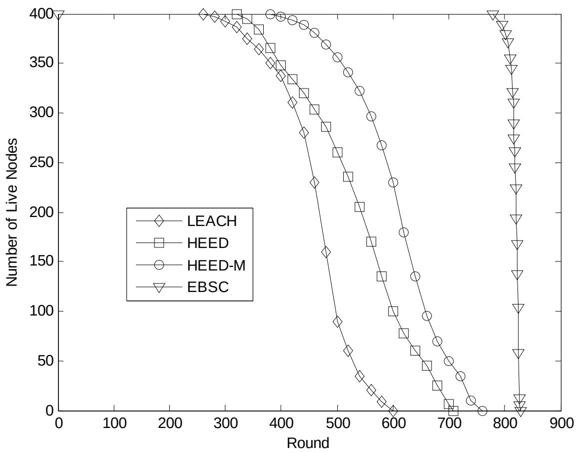

Figure 3. The network lifetime of the four algorithms

VI. Conclusion

According to the characteristics of wireless meter reading system, this paper presents an energy-balanced and energy-efficient steady clustering routing algorithm called EBSC that combines the advantage both distributed and centralized clustering algorithm. In EBSC, cluster member nodes transmit the residual energy information during cluster set-up phase, and then the current cluster head nodes select the cluster head nodes for next round according to residual energy of cluster members. The algorithm includes four parts: (1) Each cluster head node broadcasts an advertisement message. Each non-cluster head node determines its cluster for this round according to energy-distance function, and then it must transmit a message back to the cluster head node. (2) Each cluster head node elects the cluster member node with the largest residual energy to be the cluster head node for next round. (3) Each cluster member node sends its data to the cluster head node during its allocated TDMA transmission slot. Once the cluster head node receives all the data, it performs data aggregation, and then the cluster head node sends the resultant data to BS by the communication model of single hop and multi-hop that is decided according to the criterion of minimum energy consumption. (4) BS sends the message about cluster head nodes to the elected nodes for next round. Simulation results show that EBSC can well balance network energy consumption and significantly prolong network lifetime.

References

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cyirci, “Wireless sensor networks: a survey,” *Computer Networks*, vol. 38, no. 4, pp. 393–422, March. 2002.

[2] B. Krishnamachari, D. Estrin, and S. Wicker, “The impact of data aggregation in wireless sensor networks,” in *Proc. 22th Int. Conf. on Distributed Computing Systems Workshops(ICDCSW’02)*, Vienna, Austria, 2002, pp. 575–578.

[3] A. E. Rhazi and S. Pierre, “A tabu search algorithm for cluster building in wireless sensor networks,” *IEEE Trans. Mobile Computing*, vol. 8, no. 4, pp. 433–444, Apr. 2009.

[4] W. Heinzelman, A. Chandrakasan, and H. Balakrishnan, “An application -specific protocol architecture for wireless microsensor networks,” *IEEE Trans. Wireless Communication*, vol. 1, no. 4, pp. 660–670, Oct. 2002.

[5] P. K. Agarwal and C. M. Procopiuc, “Exact and approximation algorithms for clustering,” *Algorithmica*, vol. 33, no. 2, pp. 201-226, Jun. 2002.

[6] W. Heinzelman, A. Chandrakasan, and H. Balakrishnan, “Energy-efficient communication protocol for wireless microsensor networks,” in *Proc. 33rd Hawaii Int. Conf. System Sciences(HICSS)*, Hawaii, 2000, pp. 1-10.

[7] O. Younis and S. Fahmy, “HEED: a hybrid, energy-efficient, distributed clustering approach for ad-hoc sensor networks,” *IEEE Trans. Mobile Computing*, vol. 3, no. 4, pp. 660-669, Oct. 2004.

[8] O. Younis and S. Fahmy, “An experimental study of routing and data aggregation in sensor networks,” in *Proc. Int. Conf. on Localized Communication and Topology Protocols for Ad hoc Networks(LOCAN)*, Washington DC, 2005, pp. 50-57.

[9] C. F. Li, G. H. Chen, M. Ye, and J. Wu, “An uneven cluster-based routing protocol for wireless sensor networks,” *Chinese Journal of Computer*, vol. 30, no. 1, pp. 27-36, Jan. 2007.

[10] H. B. Zhang and H. Shen, “Balancing energy consumption to maximize network lifetime in data-gathering sensor networks,” *IEEE Trans. Parall- el and Distributed System*, vol. 20, no. 10, pp. 1526-1539, Oct. 2009.

[11] T. Kaur and J. Baek, “A strategic deployment and cluster-header selection for wireless sensor networks,” *IEEE Trans. Consumer Electronics*, vol. 55, no. 4, pp. 1890-1897, Nov. 2009.

[12] S. Olariu and I. Stojmenovic, “Design guidelines for maximizing lifetime and avoiding energy holes in sensor networks with uniform distribution and uniform reporting,” in *Proc. IEEE Int. Conf. on Computer Communications(INFOCOM’06)*, Barcelona, Spain, 2006, pp. 1-12.

[13] A. Jarry, P. Leone, O. Powell, and J. Rolim, “An optimal data propagation algorithm for maximizing the lifespan of sensor networks,” in *Proc. Distributed Computing in Sensor Systems (DCOSS’06)*, 2006, pp. 405-421.

[14] C. Efthymiou, S. Nikoletseas, and J. Rolim, “Energy balanced data propagation in wireless sensor networks,” in *Proc. 18th Int. Parallel and Distributed Processing Symp. (IPDPS’04)*, 2004, pp. 225.

[15] O. Powell, P. Leone, and J. Rolim, “Energy optimal data propagation in wireless sensor networks,” *Journal Parallel and Distributed Computing*, vol. 67, pp. 302-317, 2007.

[16] H. Zhang, H. Shen, and Y. Tan, “Optimal energy balanced data gathering in wireless sensor networks,” in *Proc. Int. Parallel and Distributed Processing Symp. (IPDPS’07)*, Long Beach, CA, 2007, pp. 1-10.

[17] F. J. Shang, M. Abolhasan, and T. Wysocki, “Distributed energy efficient unequal clustering algorithm for wireless sensor networks,” *Journal on Communications*, vol. 30, no. 10, pp. 34-43, Oct. 2009.