Applying a Continuous Working Time Model to Dynamic Clustering in Energy Constrained Wireless Sensor Networks

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Abstract. In Wireless Sensor Networks (WSNs), the sensor nodes are extremely energy restricted. Therefore, minimizing energy dissipation and maximizing network lifetime are the main goals of most energy efficient algorithms designed for these networks. Clustering techniques could significantly reduce the energy consumption of each individual sensor in WSNs. In this paper, we propose an energy efficient Continuous Working Time (C.W.T) strategy that could apply to the data transmission phase of the LEACH algorithm to improve its performance and save more energy. In our model, unlike LEACH, the cluster head keeps working continuously until its residual energy reaches pre-determined threshold. With this mechanism the frequency of updating clusters and the energy dissipation for new cluster head establishment can be reduced. The results of simulation demonstrate that using C.W.T model can reduce the energy consumption of each cluster effectively and increase the system useful lifetime.

Keywords: Wireless sensor networks, Energy-Efficient algorithms, Low-Energy consumption, Dynamic clustering, Network lifetime.

1 Introduction

Wireless Sensor Network (WSN) is composed of a large number of sensor nodes remotely deployed in unattended environments to monitor the surrounding area and collect data or some predefined events and send the information to the base station autonomously. The energy source of the sensor nodes are powered by batteries which are very difficult or often impossible to recharge or replace. Once sensors are deployed, the network can keep operating while the powers of batteries are adequate [1]. In addition to various architectures proposed for energy-efficient data gathering, clustering is shown to be a scalable and energy-efficient architecture for WSNs. The implementation of cluster-based network requires dividing the sensor network into smaller subnets (clusters) and selecting a candidate sensor from each cluster to act as its cluster head. The cluster head node in the cluster consumes more energy compared with other members. As depicted in figure 1, the data collected by sensors is transmitted to the cluster head and after receiving data from all members the cluster

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head filters and aggregates the data in order to extract useful information and the refined data is then sent it to the base station using a one-hop communication. Unlike other types of networks (wired, cellular, WLAN, etc.), energy conservation in WSN is a critical issue that has been addressed by significant research works [2].

LEACH (low-energy adaptive clustering hierarchy), is one of the fundamental energy-efficient clustering algorithms proposed for WSN. It plays a great role in reducing the total energy consumption of nodes and extending the useful lifetime of the network [3]. This algorithm tries to distribute the energy load, between all nodes in the network. However LEACH is round based algorithm and selects the cluster heads at the end of each round dynamically and frequently using a round mechanism. It makes the cluster head to send the advertisement message to all ordinary nodes during the cluster setup phase of every single round with additional energy consumption.

In this paper, we will refer to the sensor network model depicted in Fig.1 which consists of one sink node (base station) and a large number of sensor nodes deployed randomly over a large unattended area (monitoring field). The captured data are transferred from sensor nodes to the sink node through certain cluster heads. We assume that the sensor nodes and sink node are static and there is no mobility defined for them.

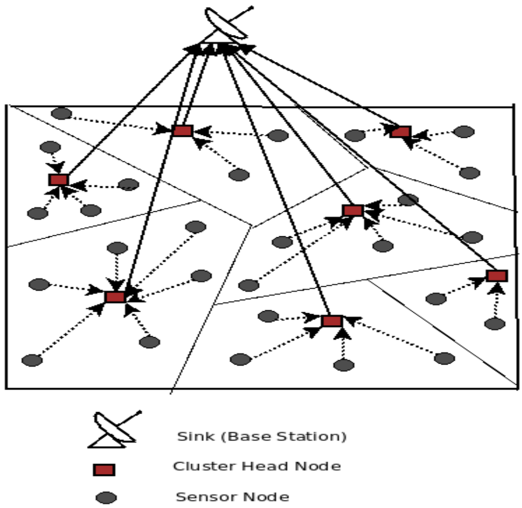

Fig. 1. Clustering technique in wireless sensor network

In this paper, we take the advantages of LEACH algorithm as a basic clustering algorithm of WSN and propose a new method to reduce the frequency of cluster updating and save the energy dissipated at the new cluster head selection phase. In our proposed model, the selected cluster head will keep working continuously until its residual energy reaches a threshold. The cluster then loses its structure and all sensors with no cluster are grouped into new clusters according to the LEACH algorithm.

The rest of this paper is organized as follows: Section 2 reviews the related works. Section 3 describes the frequent cluster head updating problem and explains our networks assumptions. Section 4 presents our Continuous Working Time (C.W.T) model. In section 5 we evaluate the performance of our model by applying to both

LEACH and S-LEACH algorithms and comparing the results with the original ones. Finally, Section 6 concludes the paper.

2 Related Works

The main goals of many clustering algorithms that have been proposed for WSNs are to maintain the energy consumption of sensor nodes and decrease the number of transmitted data to the base station. We reviewed some of the most relevant papers in this section.

Kumar et. al. [4], proposes an energy efficient clustering protocol by considering fixed size clusters. In this approach there are static clusters and the role of cluster head rotates among members. Using fixed clusters and rotating cluster head role within the cluster, in some cases, impose more transmission power to the member nodes to transmit the collected data to their cluster head. This results in an increment to the energy dissipation of member nodes. Besides, as the system ages and the number of dead nodes increases, it is difficult to control the cluster size or bound to maximize the system lifetime.

The cluster head rotation must ensure that energy consumption of all sensors is balanced over the network. In the actual application, network may contain large number of sensors that are randomly deployed in high density. It is difficult to realize the energy balance in large scale. The author in [5] uses the dynamic clustering technique to keep the energy load more balanced among the clusters. The cluster head will be replaced at end of each round frequently. This method results in additional energy consumption for the cluster setup phase and new cluster head establishment procedure.

Xiang et. al [6], also introduces an energy efficient clustering algorithm with optimum one-hop distance and clustering angle, designed for reducing power consumption between inter-clusters and intra-clusters. In this method, cluster are formed only once during the life of the WSN and the cluster heads which acts as local control center, will not replace by the candidate cluster head at the end of round until the time of being cluster head, reach the specific threshold. It could reduce the total energy consumption, however the cluster were fixed and only the role of cluster head were rotated, may cause a node use a large amount of energy to communicate with its cluster head, while there is the neighbor cluster's cluster head is close by. Therefore, using fixed clusters and rotating the role of cluster head within the cluster may require more transmit power which increase the energy dissipation of algorithm and will affect the total performance of the algorithm.

Gamwarige et. al. [7] uses predetermine *periodic time based* cluster head role rotation. The role of cluster head rotates after predetermined number of data transmission rounds. In such algorithms, if the role of cluster head changed after small number of data transmission rounds, it might cause cluster formation over head during frequent re-clustering at the cluster set up phase. On the other hand if increase the number of data transmission rounds, the cluster head depleted quickly and would not have enough energy to act as ordinary sensor nodes for the next rounds. Therefore, selecting optimum number of data transmission round is the main challenges in this approach.

3 Problem Description and Assumptions

As stated in section1, the LEACH algorithm is one of the fundamental clustering protocols in wireless sensor networks that uses clustering technique and frequent rotations of cluster heads to distribute the energy load uniformly among all nodes. However, there are some challenges on the procedure of cluster head selection and the cluster head rotation mechanism of this algorithm. The first problem is that LEACH algorithm does not consider the current energy of nodes at the time of cluster head selection which may cause the early death problem for some nodes. Also, it does not take into account the density and location of nodes which might lead to a sparse distribution of clusters. The second problem is that, in this algorithm the cluster head is selected dynamically by a round mechanism that dissipates some energy for broadcasting the advertising message to ordinary nodes or other cluster heads during set up phase.

Vejdanparast and Zeinali [5] overcome the former problem by proposing a new combinational metric that considers both residual energy and distance parameters of the nodes at the time of cluster head selection. Using the residual energy metric causes the nodes with high sources of energy to have higher chances to become cluster heads. Taking the distance metric into account leads to the selection of a candidate that is close to the densest part of the cluster (sensor-wise). The results demonstrate that the improved algorithm, which for the purpose of this paper we call S-LEACH (Selection-LEACH), could effectively reduce the total energy consumption and avoid early death problem. However, like LEACH, S-LEACH algorithm is round based and selected cluster heads are replaced dynamically at end of data transmission round. Therefore, the latter problem is still unsolved in this algorithm. In this research an energy efficient method has been developed for the data transmission phase to overcome this problem. The idea is that instead of frequently updating the cluster head, it works uninterrupted and is not replaced by other candidates until its residual energy reaches a certain threshold. It results in saving the amount of energy dissipated during the set up phase.

There are some assumptions we have to make, to proceed with our model analysis:

(1) All nodes are homogeneous and have the same resources and capabilities. They transmit the same data packet length frequently.
(2) Live sensors are immobile and have static locations.
(3) For perfect transmission of data, we assume MAC layer conditions.
(4) One-hop communication and symmetric propagation channel is considered.

4 Our Proposed Algorithm

4.1 Energy Model

We assume a simple model for the radio energy dissipation. Our model is similar to Heinzelman et al.'s [8]. Since all nodes have a uniform data generation rate and amount of energy consumed by sensing has been balanced among all sensor nodes, it is not necessary to consider the energy consumption for the data sensing.

Depending on the distance between the transmitter and the receiver, both the free space and the multipath fading models are used. If the distance is less than the threshold d_o , the free space model (fs) is used. Otherwise, the multipath (mp) model is used. The energy consumed for transmitting a *l*-bit message to distance *d* is:

$$E_{TX}(l,d) = E_{Tx-elec}(l) + E_{Tx-amp}(l,d)$$

$$= \begin{cases} l\,.E_{elec} + l_{\epsilon fs}d^2 & d < d_o \\ l.E_{elec} + l_{\epsilon mp}d^4 & d \geq d_o \end{cases} \tag{1}$$

$$d_o = \sqrt{\frac{E_{fs}}{E_{mp}}}$$

and to receive this message the radio expends:

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

where E_{elec} is the energy being used to run the transmitter and receiver circuit and E_{Tx-amp} is the energy used by transmission amplifier for an acceptable E_b/N_0 at the receiver's demodulator.

4.2 A Continuous Working Time Model

The LEACH algorithm expends some energy for the new cluster head establishment at the end of each round. If the current cluster head acts continuously as the local control center, then the frequency of the cluster head update would be reduced. On the other hand, once the cluster head is depleted, the whole cluster loses connection to the base station. Therefore, keeping the cluster head alive (operational) is the main goal for keeping the connectivity of the network. Thus, the lifetime of a cluster is defined as the time interval between the selection and death (losing the remaining energy) of its cluster head. Considering this tradeoff we propose an analytical iterative model that takes into account the working process of sensor networks in a time round manner. In this method, time is partitioned into fixed intervals of equal lengths called *rounds*. The residual energy parameter of current cluster head is considered to determine the suitable round to call for the new cluster head set up phase.

Let n_k be the number of nodes in the cluster k. The total amount of energy consumed in the cluster head during one round can be denoted as

$$E_{cost}(CH) = (n_k - 1) \times l \times E_{elec} + n_k \times l \times E_{D.A} + l \times E_{elec} + l_{\epsilon mp} \times {d_{toBS}}^4 \tag{3}$$

where E_{DA} is the energy used for data aggregation. The energy used in each ordinary (non-cluster head) node during one round is

$$E_{cost}(non-CH) = E_{elec} \times l + E_{elec} \times {d_{toCH}}^{2} \tag{4}$$

The average continuous working time (rounds) of each node that acts as a cluster head can be denoted as

$$f_{CH} \approx \frac{E_r(CH)}{E_{cost}(CH)} \tag{5}$$

The average continuous working time of an ordinary node can be denoted as

$$f_{non-CH} \approx \frac{E_r(non-CH)}{E_{cost}(non-CH)} \tag{6}$$

Based on Eqs.(5) , if the continuous working time of the first cluster head approaches f_{CH} , the residual energy of this cluster head must be the lowest and it will die quickly. Therefore, we consider the residual energy of the current cluster head at the time of threshold definition.

$$X = \frac{r_{max} - r_{current}}{\mu} \tag{7}$$

$$\mu = \frac{E_{cost}(CH)}{E_{cost}(non-CH)} \tag{8}$$

where X is defined as a combinational parameter based on the number of desired data transmission rounds and the residual energies of cluster head and cluster members. μ is the ratio of the energy cost of a cluster head to an ordinary node which is a round independent constant value. So, as the system ages and of $r_{current}$is increased, the value of X parameter is reduced.

$$\frac{E_r(CH)}{E_{cost}(CH)} \geq X \tag{9}$$

As mentioned above, the cluster head is more energy intensive than the ordinary nodes. Thus, for instance, if the node i acts as a cluster head for X rounds until energy depletion, node i could be an ordinary node for μX rounds with the same initial energy.

$$\frac{E_r(CH)}{E_{cost}(CH)} \geq \frac{r_{max} - r_{current}}{\frac{E_{cost}(CH)}{E_{cost}(non-CH)}} \tag{10}$$

The final threshold is shown as

$$E_r(CH) \geq (r_{max} - r_{current}).\, E_{cost}(non-CH) \tag{11}$$

Once the residual energy of the current cluster head becomes less than the discussed threshold, cluster set up phase will be called to establish the new cluster heads and form new clusters. Whit this proposed mechanism and continuous acting as cluster head, the frequency of updating cluster head and energy consumption for new cluster head establishment is effectively reduced. The pseudocode of LEACH algorithm and our model is given in Figure 2, and Figure 3.

```
Nodes ← set of all nodes with NotClustered status
for n in Nodes do
    p ← rand(0,1)
    if p < LEACH.threshold
        create a cluster c
        Add n to c.Nodes
        n.Status ← ClusterHead
        Remove n from Nodes
    endif
end
for n in nodes do
    c ← cluster with closest ClusterHead
    Add n to c.Nodes
    n.Status ← Clustered
end
```

Fig. 2. LEACH Algorithm pseudocode

```
for c in Clusters do
    c.Energy ← current residual energy of node c
    if c.Energy ≥ threshold
        keep cluster c as it is for the next round
    else
        for n in c.Nodes do
            Remove n from c.Nodes
            n.Status ← NotClustered
        end
    end
end
```

Fig. 3. Continuous Working Time pseudocode

Let $X_{r,i}$ be the continuous working time of an instance node i that serves as a cluster head in the r^{th}round. Based on Eqs. (3) and (4), $E_{cost}(CH) > E_{cost}(non-CH)$. Also we have $X_{0,i} > X_{1,i} > \cdots > X_{r,i}$, based on these equations, node i will be soon depleted. By considering the residual energy of node i at the time of cluster head selection, it could be replaced before complete discharge. Consequently, prevent early death problem.

5 Simulation and Performance Evaluation

In this section, we evaluate the performance of our model by applying it to LEACH and one of its improvements, S-LEACH algorithms and compare the results of simulations. Four algorithms are implemented as follows:

- LEACH algorithm, as base line of our research.
- Continuous Working Time LEACH (C.W.T. LEACH) as the improved LEACH by applying the cluster head continuous working time method in the data transmission phase.
- S-LEACH as the improved LEACH in terms of cluster head selection phase.
- Continuous Working Time S-LEACH (C.W.T S-LEACH) as our proposed model applied to the data transmission phase of S-LEACH.

To illustrate the performance of "continuous Working Time" model, the simulations are performed in MATLAB and utilized a network with 100 sensor nodes. We present the results of our experiments by applying our model on both LEACH and S-LEACH algorithms and evaluated the performance of new ones by comparing with the original ones. Moreover, to be able to compare these algorithms in our simulation we need to run them on the same networks. This is achieved by using equal random seeds for each run in all algorithms. The simulation parameters are presented in Table1.

Table 1. Experiment simulation parameters

Parameter	Value
Number of nodes	100
Monitoring area	(100,100) m
Position of Sink node	(50,150) m
Initial energy	0.3 J
Length of Data packet	4000 bits
Simulation end conditio	Number of nodes < 3
E_{elec}	50nJ/bit
$\in_{fs}$	10PJ/bit/m^2
$\in_{mp}$	0.0013PJ/bit/m^4

5.1 Network Lifetime

One of the main goals of our works is to increase the lifetime of the sensor network by reducing the total amount of energy consumption. The simulation ends when the number of live nodes becomes less than three. This means that the network loses its connectivity and is no longer operational. In this section we introduce First Node Dead (FND) and Half Node Alive (HNA) as two important parameters in terms of evaluating the performance of our model.

One of the main design features of "Continuous Working Time" model is to avoid the hot spots problem. Such avoidance can prevent the early death problems. As it is demonstrated in Figure 4, by applying our model to LEACH and S-LEACH, the life time of the network in terms of FND and HNA increases effectively compared with the original algorithms. Applying our model to both LEACH and S-LEACH algorithms improves the gradient of their diagrams, which leads to a more balanced distribution of energy loads among the clusters.

Figure 5 shows the comparison histogram, comparing FND and HNA parameters of these algorithms. This gives us an idea of the gradient of the curve. If the difference between FND and HNA is small (they are close to each other), a steep slope can be observed at the end of the curve and if the difference is noticeable, a smooth slope is observed.

Applying our model to LEACH improves the FND parameter by %44 and on S-LEACH by %7 and improves the HNA parameter by %17 and on S-LEACH %3. As stated in this paper, the S-LEACH is one of the improvements of LEACH algorithm that makes some changes in the cluster set up phase of LEACH and increases the FND parameter effectively compared with LEACH. However, this algorithm is still dynamic and works based on round mechanism. In this experiment, as we could observe, applying our model to S-LEACH could still increase the FND parameter, although, this improvement is not much comparing with LEACH.

5.2 Total Residual Energy

The energy reduction rate of the network is considered as a useful metric to compare the energy efficient algorithms in WSN. Uniform energy consumption is very important for network load balancing and less energy consumption per round which leads to a better network performance. To measure the amount of residual energy of active (live) sensor nodes generated by C.W.T LEACH and C.W.T. S-LEACH, we run these two protocols periodically. Figure 6 depicts the rate of energy reduction curves. It indicates smooth slopes for the new algorithm comparing with the original ones. This is because the energy consumption is more balanced among the clusters.

Also C.W.T LEACH and C.W.T.S-LEACH could outperform original ones during spending %68 and %84 of their initial energy respectively in term of energy saving. This could be explained by our proposed model. We keep the cluster head in each cluster working continuously in order to reduce the frequency of updating cluster head and re-clustering procedure and save the energy consumed for new cluster establishment. Thus, as illustrated in Figure 6, the amount of average residual energy in the active (live) nodes of the new algorithms is greater than active nodes of the original algorithms. Results demonstrate that applying the C.W.T model causes the energy to be consumed efficiently in the network.

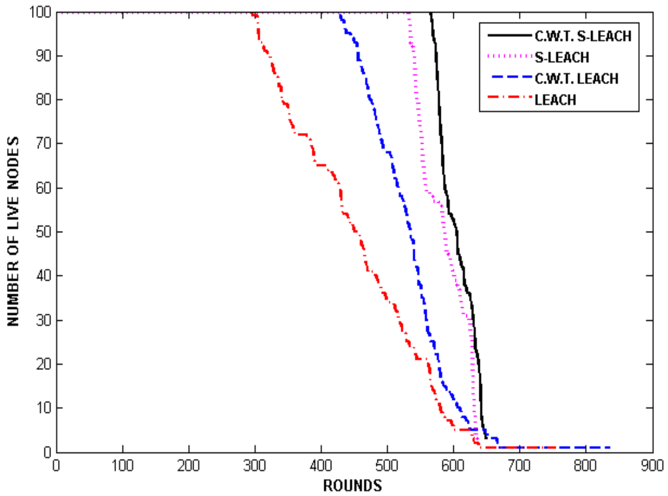

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Fig. 4. Number of active (live) nodes per round

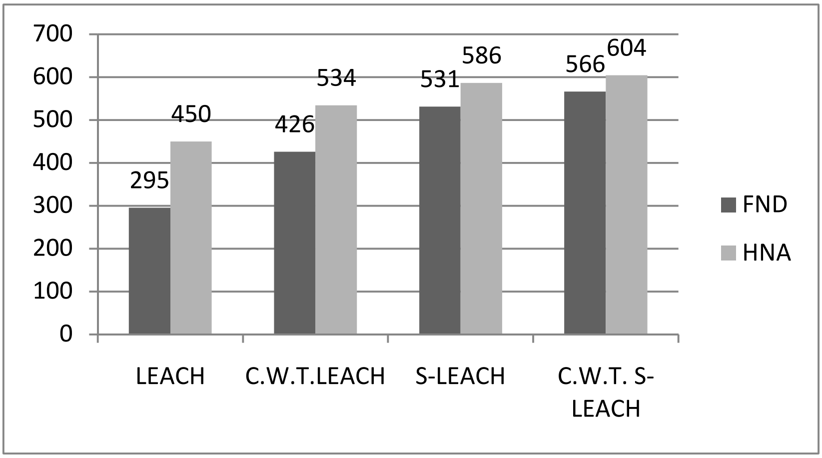

Fig. 5. Competition histogram of FND and HNA parameters

5.3 Number of Clusters Saved

In this section, as an instance, we presented the number of the clusters kept in C.W.T LEACH at end of each round and compared with original LEACH. The results are demonstrated in Figure 7. As we could observe, because of dynamic nature of

LEACH there is no cluster kept at end of each round, new clusters are formed at end of every single round. In the C.W.T LEACH algorithm, the predefined threshold is applied on the cluster head at end of each round and any cluster head that satisfy the threshold will be working continuously as the cluster head for the next round. Therefore this cluster is saved for the next round.

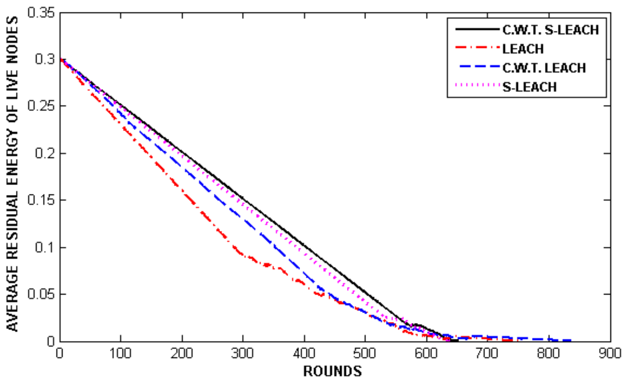

Fig. 6. Average residual energy of active (live) nodes per round

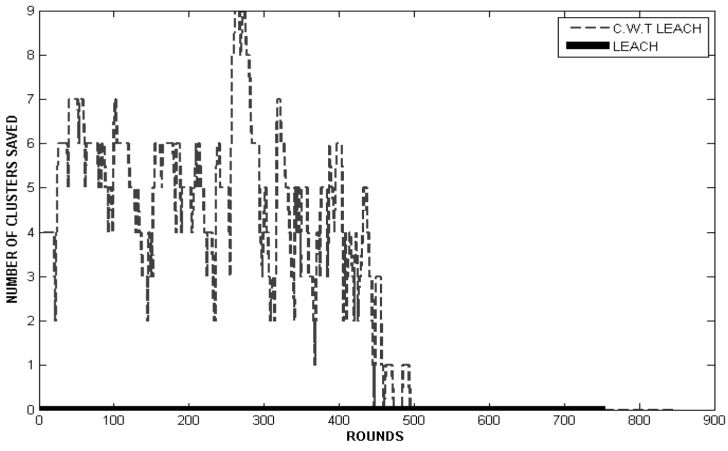

Fig. 7. Number of clusters saved at end of each round

6 Conclusion

In this paper we employ a Continuous Working Time model in the data transmission phase of the LEACH algorithm. In LEACH, the cluster head is replaced dynamically at the end of each round which entails additional energy dissipation for new cluster set up and cluster head establishment. In C.W.T model the cluster head keeps working continuously until its residual energy reaches a pre-defined threshold. If the cluster head works continuously as a local control center, then the frequency of cluster updating and the amount of energy consumed for new cluster head establishment is reduced. Therefore the lifetime of the networks is increased. We assume the channel is lossless and don't consider the packet loss and retransmission in our implementation. The performance evaluation shows that by applying our model to the data transmission phase of both LEACH and S-LEACH, the lifetime of the network in terms of FND and HNA is increased effectively.

References

1. Anastasi, G., Conti, M., Francesco, M.-D., Passarella, A.: Energy Conservation in Wireless Sensor Networks: A Survey. Ad Hoc Networks 7, 537–568 (2009)
2. Merrett, G., Harris, N., Hashimi, B., White, N.: Energy Manage Reporting for WSNs. Sensors and Actuators 142, 379–389 (2008)
3. Nayebi, A., Sarbazi-Azad, H.: Performance Modeling of LEACH Protocol for Mobile WSN. Journal of Parallel and Distributed Computing 71, 812–821 (2011)
4. Kumar, A., Chand, N., Kumar, V.: Location Based Clustering in WSN. World Academy Science, Engineering, Technology 60, 1977–1984 (2011)
5. Vejdanparast, A., Zeinali Kh., E.: A New Approach to Clustering with Respect to the Balance of Energy in Wireless Sensor Networks. In: Bravo, J., López-de-Ipiña, D., Moya, F. (eds.) UCAmI 2012. LNCS, vol. 7656, pp. 25–32. Springer, Heidelberg (2012)
6. Xiang, M., Shi, W., Jiang, C., Zhang, Y.: Energy Efficient Clustering Algorithm for Maximizing Lifetime of WSN. Int. J. of Electronic and Communication 64, 289–298 (2010)
7. Gamwarige, S., Kulasekere, C.: Optimization of Cluster Head Rotation in Energy Constrained WSN. In: IFIP Int. Conference on Wireless and Optical Communications Networks, pp. 1–5 (2007)
8. Heinzelman, W., Chandrakasan, A., Balacrishnan, H.: An Application-Specific Protocol Architecture for Wireless Microsensor Networks. IEEE Trans. on Wireless Communications, 660–670 (2002)
9. Chen, J.: Improvement of LEACH Routing Algorithm Based on Use of Balanced Energy in Wireless Sensor Networks. In: Huang, D.-S., Gan, Y., Bevilacqua, V., Figueroa, J.C. (eds.) ICIC 2011. LNCS, vol. 6838, pp. 71–76. Springer, Heidelberg (2011)