Maximizing the Network Lifetime of Clustered-based WSN Using Probability of Residual Energy

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Abstract**—** The deployment of Wireless Sensor Network(WSN) must be done with some kind of advanced techniques so that it can mitigate the energy constraints. An existing, clustered-based routing protocol known as Low-Energy Adaptive Clustering Hierarchy (LEACH) was studied, the outcome is an improved algorithm based on LEACH. The performance of these algorithms was studied through simulations using OMNeT++. In the original LEACH, the Cluster Heads selections were based on a distributed algorithm. For the modified algorithm, the improvement was done in the Cluster Head selection process. The selection process takes into account the residual energy of each node and used its probability outcome for the determination of the threshold value for next round. The results concluded that the performance of the modified algorithm is better than the original LEACH, the outcome will result in maximizing network lifetime.

Keywords: WSN, LEACH, network lifetime, power consumption, modified algorithm, performance

I. Introduction

WSN consists of a collection of nodes with sensing, wireless connectivity and computing capabilities. These sensor nodes are scattered in a prescribed environment and located at a distant from the users. Architecturally, WSN includes three entities:(1) sensors which make up the network, its function is based on taking local measures through a discrete system, creating a wireless network in an unattended environment, gathering data, aggregating and transmitting them to the base station; (2) base station: the data gathered by the sensor field is sent to the base station as the final destination through a multihop operation; (3) End user: an entity that have an interest in acquiring the data regarding a specific phenomenon. WSN facilitates the process of monitoring the physical and environmental conditions such as temperature, sound, vibration, pressure, motion, chemical and pollutants. In the case of smart environment, it relies on WSN sensor network for information gathering within a building, shipboard, habitat monitoring, intelligent transportation system, healthcare monitoring, home surveillance, traffic control and many more [2][3]. Hence, WSN is a combination of sensing, processing and communication technologies. Each node may be active, idle, sleeping or dead. Thus, network lifetime is a measure of how long the network survived on the existing energy supply. It is a fundamental characteristic to evaluate a goodness of a sensor network [4]. The effectiveness of WSN depends on the sensor on each node. If the sensor node is 'alive', it then performs its function to sense, process information and communication. Two conditions that affect the network lifetime: how much energy is consumed over time and how much energy is available for its use beyond that time. The classical approached dealing with network lifetime is known as clustering. A high performance WSN is highly dependent on energy-efficient clustering routing algorithm [5]. The development of a clustering-based hierarchy protocol that optimized the energy-efficiency in WSNs is called Low-Energy Adaptive Clustering Hierarchy (LEACH) [6]. In this paper we proposed an improvement scheme by modifying the existing features of LEACH through effective energy distribution and identify new Cluster Head (CH) through a systematic probability of residual energy determination.

II. LEACH algorithM Analysis

A. Description

The cluster-based model of WSN, LEACH is better than single-hop or multi-hop model. The CH based routing algorithm was proposed by Heizenman *et al* [7] that optimizes the energy efficiency in WSNs. In this algorithm, the cluster members elect CH which could avoid excessive energy consumptions [8]. LEACH is a self-organizing, adaptive clustering protocol that uses randomization to distribute the energy load evenly among the sensors in the network. The nodes organize themselves into local clusters, with one node acting as the CH. If the CH were chosen a priori and fixed throughout the system lifetime, it is easy to see that the unlucky sensors chosen to be CH would die quickly, ending the useful lifetime of all nodes belonging to these clusters [7]. LEACH is made up of two phases: set-up phase and steady-phase. In the set-up phase, sensors elect randomly among themselves a local cluster-head with a certain probability. The

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result is a balanced energy dissipation scheme across the whole network. The optimum number of CH is 5% of the total nodes. After the CHs selection, the heads advertised to all sensor nodes in the network that they are the new cluster-heads. Once the nodes receive the advertisements, they decide which head they belong to. In steady-phase, sensors sense and transmit data to the base through their CH. After a certain period spent in the steady-state, the network goes into the set-up phase again and enters another round of selecting CH.

B. Election of Cluster Head (CH)

The election process for CH is determined through a selection of a random number between 0 and 1. If this number is lower than a threshold *T(n),* the node becomes CH. The threshold, *T(n)* is determined according to the expression,

$$T(n) = \begin{cases} \dfrac{p}{1 - p(r \bmod \frac{1}{p})}. & if \quad n \in G \\ 0 & otherwise \ . \end{cases} \qquad (1)$$

for nodes that have not been CH in the last $1/p$ rounds, otherwise *T(n)* is zero. Here p is the desired percentage of CH compared to the total number of nodes, and r is the current round. Using this algorithm, each node becomes a CH approximately once within $1/p$ rounds. After ($(1/p) - 1$) rounds, $T(n) = 1$ for all nodes that have not yet been CH. When a node has elected itself as CH, it broadcasts an advertisement message telling all nodes that it was elected as CH. Non-CH used these messages from the CH to choose the cluster they want to be in this round which is based on the received signal strength indicator of the advertisement packet. The CH normally received data packets from the nodes that would like to join the cluster. Depending on the number of nodes in the cluster, CH then creates a TDMA schedule arranging each node when to transmit the data packets. This schedule is then broadcasted to all nodes within the cluster.

C. Data Transmission

Once the clusters are created and the TDMA schedule is fixed, nodes can start transmitting data packets. Nodes send their data to their respective CH at most once per frame during their allocated transmission slot. Assuming nodes always have data to send, they send it during their allocated transmission time to the CH. This transmission uses the minimum amount of energy based on the received strength of the CH advertisement. The radio of each non-CH can be turned off until the node's allocated transmission time is reached, thus reduced energy dissipation. The CH must keep its receiver, ON to receive all the data from the nodes in the cluster. Once all the data had been received, the CH performs optimization functions. This resultant data packet, is then transmitted to the base station. This is the steady-state operation of LEACH networks. After a certain period of time, which is determined a priori, the next round begins with each node expecting to become a CH for the next round.

D. Limitation of LEACH

LEACH performance is outstanding, with some deficiencies attributed to it. LEACH is less efficient for large-scale networks, which is a scalability issue. The network enforced a fixed percentage of CH for any size network (5%), which may lead to concentration of CH in one region of the network. The protocol make some assumptions such as, all nodes communicate over a single hop to the base station, uniform energy dissipation for both CH and non-CH nodes in any given round and finally all nodes start with equal energy residual levels.

III. The Modified Protocol

A. Overview

LEACH uses a distributed algorithm for the formation of the cluster head node, each node make decision by itself without a central control. In this case, the cluster head is selected randomly and nodes become the cluster head in turn when cluster heads have the same initial energy. The reference indicator is the number of times for each node to become the cluster head. However, after several rounds, the distribution of energy in the network will be uneven and cluster head selection will become unreasonable [8]. In this proposed modified LEACH algorithm, we improved the cluster head selection process by taking into account the residual energy in each member node after each rounds while the steady-state is identical with LEACH. Different from LEACH, we have three phases in this proposed algorithm which include set-up phase, steady-state phase and pre set-up-next-round phase.

B. Modified Algorithm for CH Selection

1) CH selection and residual energy probability

The selection of CH in the original LEACH was done randomly. The result of that random selection produced unbalanced energy distributions in all nodes. As a consequence of that the nodes increases the total energy consumption of system. Residual energy represents an amount of usable energy available for future operation. Typically the amount of residual energy will always drop progressively with time. In another scenario, the residual energy will always drop as the number of active nodes increases. It also drops as increasing number of rounds. Hence the residual energy can always be considered as viable parameters for finding the best CH at a given time. Hence in order to evenly distribute the energy load among all the nodes in the network, we introduce the threshold depending on the node's residual energy and the optimum cluster head selection probability to optimize the cluster head selection. The proposed algorithm utilizes probability function while considering the residual energy for cluster configuration, whereas LEACH only utilizes probability function. In case the nodes do not have the same amount of energy for next round, the nodes with higher residual energy will become a cluster-head more often than nodes that have less energy, ensuring that all nodes die approximately at the same time. This can be achieved by setting the probability of being elected as CH as a function of a node's energy level relative to the aggregate energy remaining in the network. The threshold value will depend on the amount of residual energy such as,

$$T(n) = \begin{cases} \frac{p_{opt}}{1 - p_{opt} * (r \bmod \frac{1}{P_{opt}})} \cdot \frac{E_{residual}(t)}{E_{total}(t)} & if \quad n \in G \\ 0 & otherwise. \end{cases} \quad (2)$$

Here, p_{opt} is the probability of node's optimum CH selection, $p_{opt} = (k_{opt}/nr)$, k_{opt} is the optimum number of clusters in current round, G is the set of nodes which have never been the CH in the last $1/p_{opt}$ round, $E_{residual}$ is the residual energy of node, E_{total} is the initial energy of node. After reducing the threshold, the probability of residual energy of nodes to be a CH increases.

$$E_{total}(t) = \sum_{n=1}^{N} E_{residual\,(t)} \quad (3)$$

where E_{total} is the total energy of entire network. Using these probabilities, the nodes with higher energy will become CH.

2) Set-up phase

Each node generates a random probability (p_n) at the beginning of a new round and computes the threshold value $T(n)$ by using Eqn.(2). If $r = 1$ (first round) and $E_{residual}$ for each node are the same, and $p_n < p_{opt}$, the node is selected as a CH. It then broadcasts an advertised message to neighboring nodes. The neighboring nodes response by sending a "join REQ" message to the nearest CH. CH will receive the "join-REQ" message and build a cluster member list and TDMA schedule. Subsequently it broadcast them to the neighbor nodes.

3) Steady-state phase

The time-line of the proposed modified LEACH algorithm is shown in Fig. 1. Similar to the original LEACH, the steady-state operation is divided into frames. Main activities are sensing and transmission of sensed data. Each sensor nodes senses and transmits the sensed data to its cluster head according to TDMA table. In addition, for next round that going to occur it is required for the cluster node to transmit together their current energy and their ID's. When data and energy status has been received, the CH performs data fusion and aggregation in order to reduce the amount of data. Finally, each CH transmits data to BS along the CH-to-CH routing path which have been formed during setup phase.

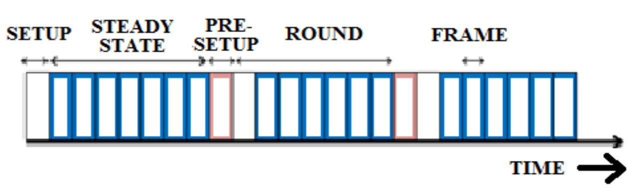


Fig. 1. TDMA Frame of the Modified Algorithm

4) Next Round Pre set-up phase

CH sends the value of its residual energy to the base station. Base station will then calculate the total residual energy value (E_{total}) of the network, and distributes E_{total} back to CH. Each CH then broadcasts E_{total} to its cluster nodes. Each nodes save the value of E_{total} for the next computation of $T(n)$ and the current round is terminated. Fig. 4 shows a flow chart for next-round-pre setup phase in the modified algorithm.

IV. SIMULATIONS AND RESULTS

A. Simulation Parameters

The performance of the networks is carried out by simulations using Omnet++ using the framework as shown in Figure 2. Hence, it would be very important to analyze which parameters that will affect the operation of the protocol. After choosing the parameters it can be useful to differentiate what kind of results should be obtained and why it is so. In the simulation, the network lifetime will be considered by analyzing the first node dead (FND) and half node dead (HND) of the network. Lifetime is traditionally defined as the amount of time between the start of dataflow in the network and the time a certain percentage of nodes have run out of energy. For the purpose of simulation, the simple radio model was used [7]. The model assumed energy dissipation of the electronics part, E_{elec} given as 50 nJ/bit to run the transmitter or receiver circuitry and E_{amp} as 100 pJ/bit/m^2 for the transmitting amplifier in order to achieve an acceptableSignal to Noise Ratio, (E_b / N_o). The first order radio model is as shown in Figure 4 and other parameters of interest are described in Table 1.

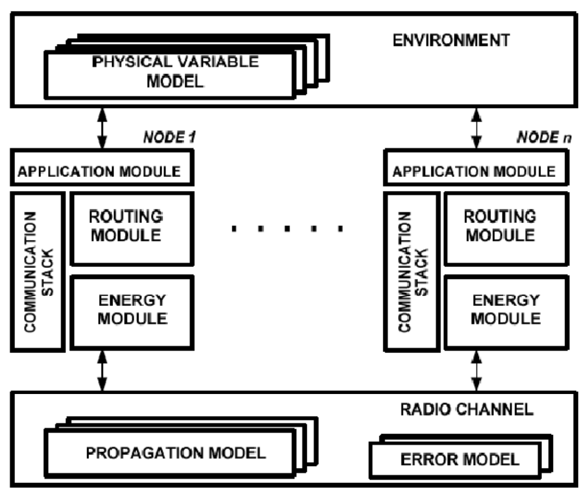


Fig. 2. WSN Simulation Model

B. Result and Analysis

This subsection shows a comparison with the results of the simulations of LEACH and the modified algorithm. The evaluated results are related to the number of rounds done until half of the nodes are dead (HND) or when the first node is dead (FND), whichever is applicable.

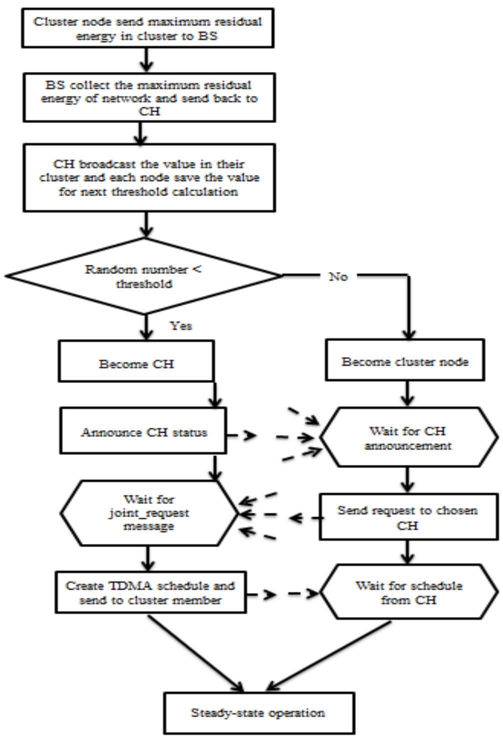


Fig. 3. Next-Round-Pre setup phase for modified algorithm

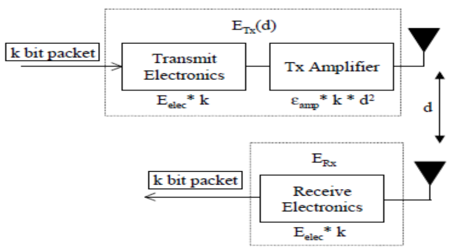


Fig. 4: First order radio model

1) First Node Dead

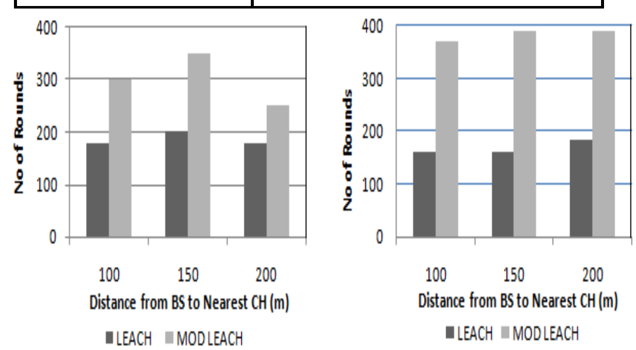
In the case of a short steady phase and a small area network the modified algorithm shows better results, which achieves even more than 2 times the lifetime of the LEACH as shown in Figure 5. When the network size is increase, the modified algorithm shows a decrement in term of network lifetime but still better than the original LEACH. It can be observed from Fig. 5 and 9 that the longer steady-state phase, the network lifetime for both protocol is reduced. The proposed modified LEACH prolong the network lifetime. The consideration of node residual energy during cluster head selection processing can maintain the balanced energy consumption of the sensor network.

2) Half Node Dead

Next, the analysis of half node dead is done to observe the overall performance of LEACH and the modified algorithm. The graphs illustrate the performance comparison between the modified algorithm and the original LEACH in terms of the number of rounds achieved until half of the nodes are dead. By analyzing the result from Figure 7 and 9, the modified algorithm still achieve a higher number of rounds but with less value as the TDMA frame increases. Also it can be observed that, the network lifetime for both protocols become worse as network size increase. As the network size and TDMA frame increase, the result for both protocols become closer to each other.

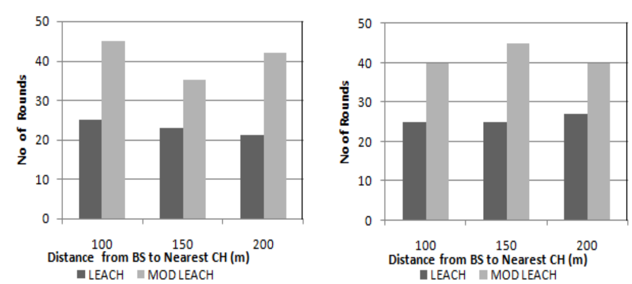
Table 1: Simulation parameters

Parameter	Value
Network Grid (M x M) Base Station Initial Energy Node Distribution(N)	(500, 500), (1000, 1000) (1500, 1500) 100, 150, 200 meter 0.5 J/battery/node 100 nodes randomly distributed
Rounds (frame) Broadcast packet size Packet header size	5, 10, 20, 25 TDMA frames 25 bytes 25 bytes
Tx energy consumption ($E_{TX\text{-}elec}$) Rx energy consumption ($E_{RX\text{-}elec}$) ($E_{TX\text{-}elec} = E_{RX\text{-}elec} = E_{elec}$) Amplifier energy consumption (E_{amp})	50 nJoule/bit 50 nJoule/bit 100 pJ/bit/m^2



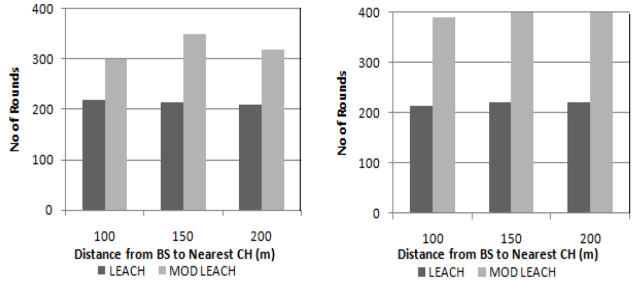
(a) Size: 1500x1500, Frames: 5 (b) Size: 500x500, Frames: 5

Fig. 5. FND for different network sizes and 5 TDMA frames



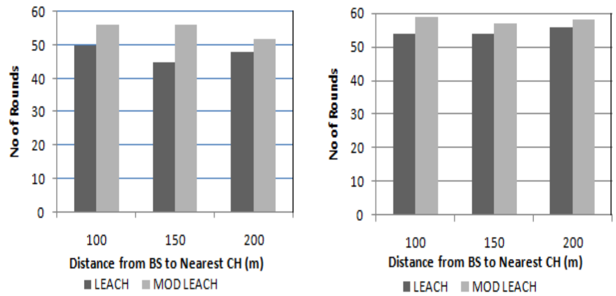
(a) Size: 1500x1500, Fr: 25 (b) Size: 500x500, Fr: 25

Fig. 6. FND for different network sizes and 25 TDMA frames



(a) Size: 1500x1500, Fr: 5 (b) Size: 500x500, Fr: 5

Fig. 7. HND result for different network size and 5 TDMA frames

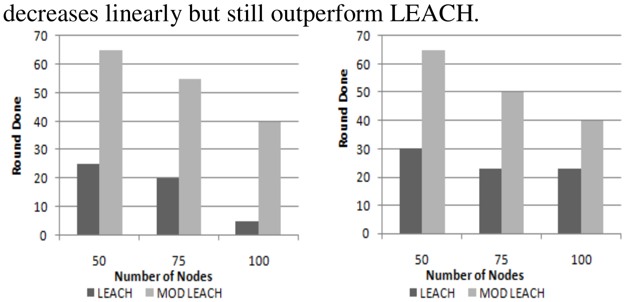


(a) Size: 1500x1500, Fr: 25 (b) Size: 500x500, Fr: 25

Fig. 8. HND result for different network size and 25 TDMA frames

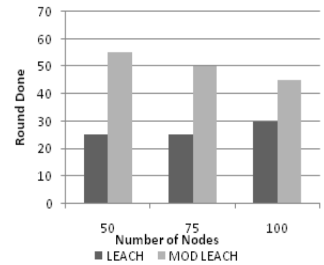
3) Effect of the Number of Nodes to the Network Lifetime

Another simulation was carried out is to study the effect of different number of nodes on the network lifetime. In this simulation 50, 75 and 100 nodes implemented in 500 x 500 m^2, 1000 x 100 m^2 and 1500 x 1500 m^2 network size. As depict in Fig. 9, when the number of nodes increases, the network lifetime decrease for both protocols. For larger number of nodes and bigger network size, the network lifetime closer to each other but there is still an improvement shows by modified algorithm. It can be seen here, LEACH shows a stable network lifetime for bigger network size. Meanwhile for modified algorithm, it shows that network lifetime decreases linearly but still outperform LEACH.



(a) 500x500 (b) 1000x1000

Fig. 9. FND for different number of nodes



(c) 1500x1500

Fig. 9. FND for different number of nodes (cont)

C. *Percentage Improvement of Modified Algorithm compared to LEACH*

From the simulation exercises shown before, the performances of the modified algorithm were compared to LEACH accordingly. It can be seen (Table 2) that the network sizes and the TDMA frames do affect the performance of WSN in terms of maximization of network lifetime. Modified algorithm performed much better with short steady state phase, smaller network size and shorter BS to nodes distances. This is expected due to the the energy used to aggregate the data is less with shorter distance. When steady state becomes longer, the improvement is reduced, but still surpassed that of LEACH.

Table 2. Improvement of network lifetime in % , Modified algorithm to LEACH for FND

	Modified Algorithm Improvement					
Area(m^2)	500 x 500			1500 x 1500		
BS distance (m)	**100**	**150**	**200**	**100**	**150**	**200**
5 frames (%)	133	145	122	81	111	56
25 frames (%)	85	109	77	83	67	86

For HND, the shorter steady state phase shows only a slight increment compared to LEACH. The improvement becomes worse when BS distance is farther, as shown in Table 3.

Table 3. Improvement of network lifetime in % , Modified Algorithm to LEACH for HND

	Modified Algorithm Improvement					
Area (m^2)	500 x 500			1500 x 1500		
BS distance (m)	**100**	**150**	**200**	**100**	**150**	**200**
5 frames (%)	67	65	71	43	60	50
25 frames (%)	9	6	4	12	17	10

V. CONCLUSION

The implementation of WSNs architecture is done to study the performance of LEACH and the modified algorithm. Using this implementation the performance of both protocols are evaluated with different simulation scenarios of large scope clustered-type networks. The study on power consumption and improvement is performed through the analysis of the network behavior, where it is obtained by through extensive simulations with the varieties of values specific to the parameters of the WSN. The improvement of LEACH has solved some of its drawbacks by introducing a technique in CH selection using the probability of residual energy and new threshold calculation. This algorithm has been implemented in OMNeT++ . The evaluation of the simulation scenarios has been done by using a several parameters. First testing is done using various TDMA frames in different network size and BS distance. In this simulation, more improvement can be observe when the TDMA frames is shorter, smaller network size and shorter BS distance. Second testing is achieved by comparing the number of nodes and network size with the evaluation of FND and HND parameters. It shows that results are better when the number of nodes or network size is smaller. As we increase the number of nodes and network size, the network lifetime is worse. Still, the performance of modified algorithm has improved as compared to LEACH in term of its network lifetime.

References

[1] H. Karl and A. Willig, Protocol and Architecture for Wireless Sensor Networks, Wiley, 2005.

[2] L. F, "Smart Environments: Tecnologie, Protocols and Application," in *Wireless Sensor Network*, New York, 2004.

[3] Q. Ali, A. AbdulMaowjod and H. Mohammed, "Simulation and Performance Study of Wireless Sensor Network (WSN) Using MATLAB," *Iraq J. Electrical and Electronic Engineering,* vol. 7, no. 2, pp. 112 - 119, 2011.

[4] I. Dietrich and F. Dressler, "On the Lifetime of Wireless Sensor Network," *ACM Transaction on Sensor Network,* vol. 5, no. 1, pp. 1 - 38, 2009.

[5] Y. Liu, N. Xiong, Y. Zhao, A. Vasikalos, J. Gao and Y. Jia, "Multi-Layer Clustering Routing Algorithm for Wireless Vehicular Sensor Network," *IET Communication,* vol. 4, no. 7, pp. 810 - 816, 2010.

[6] W. Heizenman, A. Chandrakasan and H. Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Microsensor Networks," in *Proceedings of the 33rd Hawaii International Conference on System Sciences*, Hawaii, 2000.

[7] W. R. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Microsensor Networks," in *Proceedings of the 33rd Hawaii International Conference on System Sciences*, Hawaii, 2000.

[8] L. Tao, Z. Qing-Xin and Z. Luqiao, "An Improvement for LEACH Algorithm in Wireless Sensor Network," in *2010 5th IEEE Conference on Industrial Electronics and Application*, 2010.

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

[10] T. Voigt, A. Dunkels, J. Alonso, H. Ritter and J. Schiller, "Solar-aware Clustering in Wireless Sensor Networks," in *Proceedings of the Ninth International Symposium on Computers and Communications 2004*, 2004.