A Hybrid Energy-Efficient Routing protocol for Wireless Sensor Networks

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***Abstract*—The usage and deployment of Wireless Sensor Networks (WSN) is rapidly increasing in many different monitoring and control applications. In the majority of these applications, energy is a key factor in sensor networks since the sensor nodes are battery powered and hence have limited resources of energy. In this context, choosing a proper energy-efficient routing technique can increase the network life time. In this paper, a new Hybrid Energy-Efficient (HEE) routing protocol is proposed. HEE uses Direct Transmission (DT) and Minimum Energy Transmission (MTE) which are two of the simplest methods in terms of computational complexity. However the design of routing techniques is highly dependent on the application and the performance may vary based on environmental parameters. The novel proposed method is applicable for different networks regardless of the size and distances between the nodes and also with different parameters such as number of nodes and message length. Simulation results show how HEE performs more efficiently in terms of energy consumption when comparing to DT and MTE.**

***Index Terms*—Wireless Sensor Networks (WSN), Energy Analysis, Routing Protocols**

I. INTRODUCTION

The Wireless Sensor Network (WSNs) is an emerging technology which is recently used in a wide range of applications such as home automation, environmental and habitat monitoring, military systems, security systems and industrial automation [1]. WSN is a combination of computer networks, wireless systems and microelectronic technology. It is also a replacement of the traditional wired sensors where the processed data are broadcasted into the network rather than raw data. As a result there is no need to have a central processor since the processing is performed locally. This local processing gives the node the ability of acting and deciding independently regardless of the network constraints. WSN is intended to acquire and report various physical characteristics of the environment such as temperature, light, humidity acceleration and etc.

Intelligent or smart sensors are also referred to the WSN since the nodes are capable of self-organizing, self healing, auto-routing.

WSN is a network of hundreds or even thousands of the tiny sensor nodes which are deployed in the environment to monitor physical characteristics. In the network, there is a special node called gateway which is dedicated to collect the information from the network and forward them to a PC or other networks for further processing. Like all the wireless networks, there may be some places which are not in the coverage of the gateway. In this case, the nodes, which are out of the coverage of the gateway, should be able to send the information via other intermediate nodes. This is called routing techniques in which the nodes will choose the optimal path in order to reach the gateway.

Typically sensor nodes are powered by batteries and hence they are energy constrained. Therefore a proper network design should be considered in order to save not only the energy but also the other resources in the nodes such as memory. In WSNs, power consumption mainly happens in three sections: sensing, communication, and data processing. Due to the environmental constraints, most of the times the batteries can neither be replaced or recharged. Among those sections, the communication module is the most energy consuming section in a node.

Routing techniques mainly use the transceiver section and hence as packet of data can be transmitted through different paths, making decision for selecting a proper path has an important effect on the total energy consumption of the network.

There are many researches in which design principals and technical approaches of routing protocols of WSNs have been discussed [2]–[8]. Among those, Low Energy Adaptive Clustering Hierarchy (LEACH) [9]–[11] becomes very popular since it performs well in terms of energy consumption. There are also some improvements on LEACH where each attempts to improve one aspect of the algorithm [12]–[23]. However, all the mentioned techniques require a considerable amount of computation which, therefore, affects the network life time.

In this paper, two popular and simple routing protocols,

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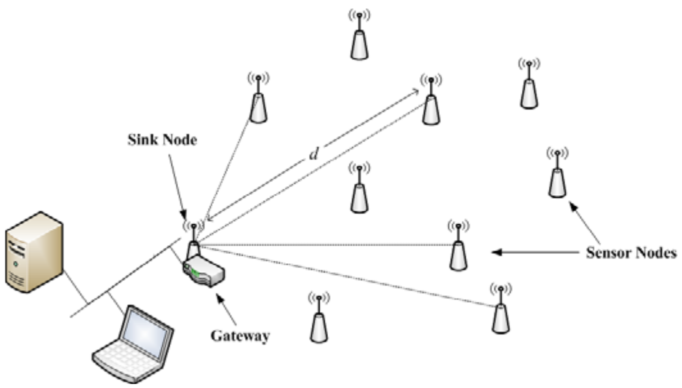

Figure 1: Direct transmission method in a distributed WSN

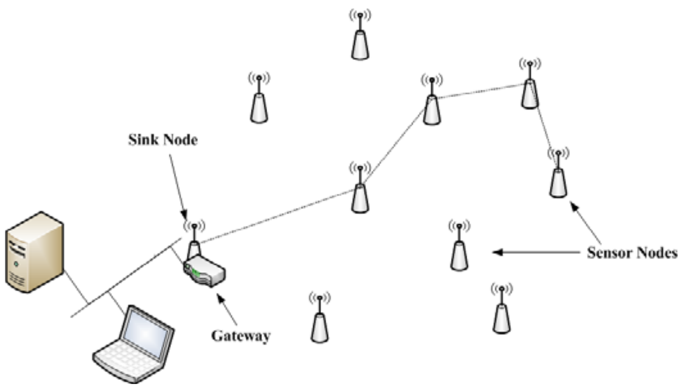

Figure 2: MTE Technique

namely Direct Transmission (DT) and Minimum Energy Transmission (MTE), are combined and a new Hybrid Energy-efficient (HEE) routing protocol is proposed. The reason of utilizing DT and MTE is the simplicity and also the easy implementation of them in practice. In previous study of the authors the effect of several parameters such message length, number of nodes, network size and transmission frequency on DE and MTE in linear (one-dimensional) WSN for an industrial application have been studied and analyzed [24]. This was the main motivation to develop and extend the previous analysis to propose HEE for a two-dimensional case. The simulation results show that the total energy consumption of HEE is even less than the DT and MTE.

However, as mentioned in [24], it should be noted that choosing a proper routing technique is highly dependent on the application, that is, although a technique may generally perform well, it may not work proficiently in some applications.

This paper is organized as follows: Section II gives a summary of DT and MTE protocols followed by simulations. Section III presents the proposed routing techniques algorithm. Section IV demonstrates the simulation of HEE and comparison with DT and MTE and finally, section V concludes the paper.

II. ANALYSIS OF DIRECT AND MTE PROTOCOLS

A. Direct Transmission (DT)

In direct transmission each nodes send its own data directly to the gateway or sink node that is responsible for collecting the data from the network (Figure 1). It is clear that each node consumes some amount of energy to transmit the data to the gateway. This amount of energy is corresponding to the distance between the node and gateway. It can be implied from equation 1 that the expended energy will be increased as the distance between the transmitter and receiver is far. Therefore, this method is not efficient for large scale environments such as forests, lakes, etc. since there is a limitation in the coverage area of the gateway.

The amount of energy consumed in direct transmission in order to send k-bit packet of data is mainly in the electronic circuit and transmitter amplifier, that is [10]:

$$E_{direct} = k \times (E_{elec} + \in_{amp} \times d^2) \tag{1}$$

where k is the number of bits in a packet, E_{elec} is the consumed energy in the electric circuitry to process one bit, $\in_{amp}$ is the amplification energy in transceiver and d is the distance between the transmitter and receiver. Here it should be mentioned that, Friss free space [25] model has been used in the entire of this paper. That is, all the distances between the transmitter and receiver are assumed to be less than the $d_{crossover}$ as discussed in [24].

B. Minimum Transmission Energy (MTE)

In MTE, the nodes transmit the data via intermediate nodes. That is instead of having one high energy transmission; we will have several short distance and low energy transmissions (Figure 2). Therefore each node must find the shortest path in order to reach the gateway.

Therefore the energy consumed in MTE for a transmission from node n to gateway contains n transmits and $n-1$ receives via intermediate nodes, that is:

$$E_{ntoB(MTE)} = k \times \left[(2n-1)E_{elec} + \in_{amp} \sum_{i=1}^{n} d_i^2 \right] \tag{2}$$

$E_{ntoB(MTE)}$ is the required energy in order to send k-bit data from node n to the gateway via n nodes in the path.

C. DT and MTE Implementation

For Implementation of MTE routing technique, an algorithm which is able to find the shortest path from source node to the gateway or base station (BS) is developed. At the beginning the nearest neighbor of node n and its distance to the base station will be found. If the distance is less than the distance of the node n to base station, then it will be selected as the first node in the path, otherwise the next nearest neighbor will be replaced as we are going away from the base station. It will be continued until the base station reached. This is shown in Figure 3 where there is a network of $100m$ by $100m$ with base station located in $(0, 0)$.

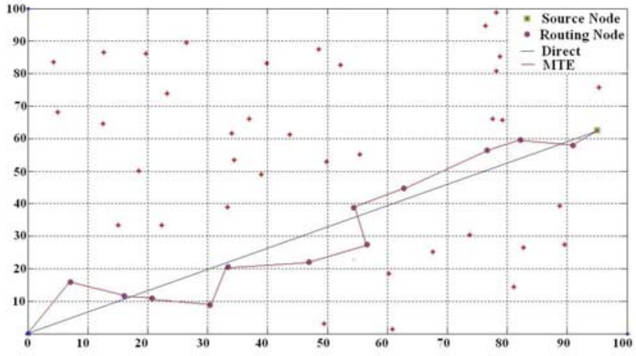

Figure 3: Developed algorithm for MTE implementation

Table I: Total energy dissipation of the system for different network size

	Network Size		
	40mx40m	120mx120m	160mx160m
$E_{direct}(J)$	0.0012	0.0052	0.0089
$E_{mte}(J)$	0.0043	0.0054	0.0069

In this research for all simulations, transmitter/receiver electronic energy is assumed to be $E_{elec} = 50nJ/bit$, and amplifier energy consumption is $\in_{amp} = 100pJ/bit/m^2$ [10]. Network size is the area in which sensor nodes are deployed. Length of message or number of bits (k) is assumed to be $k = 100$ bits and simulation will be carried out with 50 sensor nodes which are randomly deployed in the network area. Total amount of energy dissipation in each routing method can be computed, by adding up the energy consumption of each node.

The simulation has been done for three different network size like: $40m \times 40m$, $120m \times 120m$ and $160m \times 160m$, while other parameters have been kept constant. The reason for selecting those numbers is that when the network size is $120m \times 120m$, the energy consumption of both DT and MTE is almost identical. This is because of the critical distance $(d_{critical})$ discussed in [24]. Table I demonstrates the total energy dissipation for different network size. For the networks which are less than the $d_{critical}$ direct transmission consumes less energy than the MTE. More information about the critical distance and its parameters can be found in [24].

III. HYBRID ENERGY-EFFICIENT (HEE) ROUTING PROTOCOL

This section identifies the proposed HEE routing protocol which is the combination of the DT and MTE. In section 3, efficiency of both protocols for different sizes of the network has been analyzed and the results declared that direct method is more efficient for the small networks while MTE performs more efficient in large areas. Considering the above facts brings the idea to the mind that how the combination of these two methods would operate.

The procedure of calculating the energy dissipation of the new routing protocol is started by choosing one node as a source or starting point. In this stage the amount of required energy using direct method for transmission will be calculated. Then the required energy of the MTE method, in order to transmit the same packet of data from same source node to the base station, will be computed. Therefore, by comparing these two values, the one which is more efficient can be selected as a desired method of transmission for this specific node. The process will be repeated for all the nodes in the network (Figure 4). As a result some nodes may use DT and others may use MTE for the transmission.

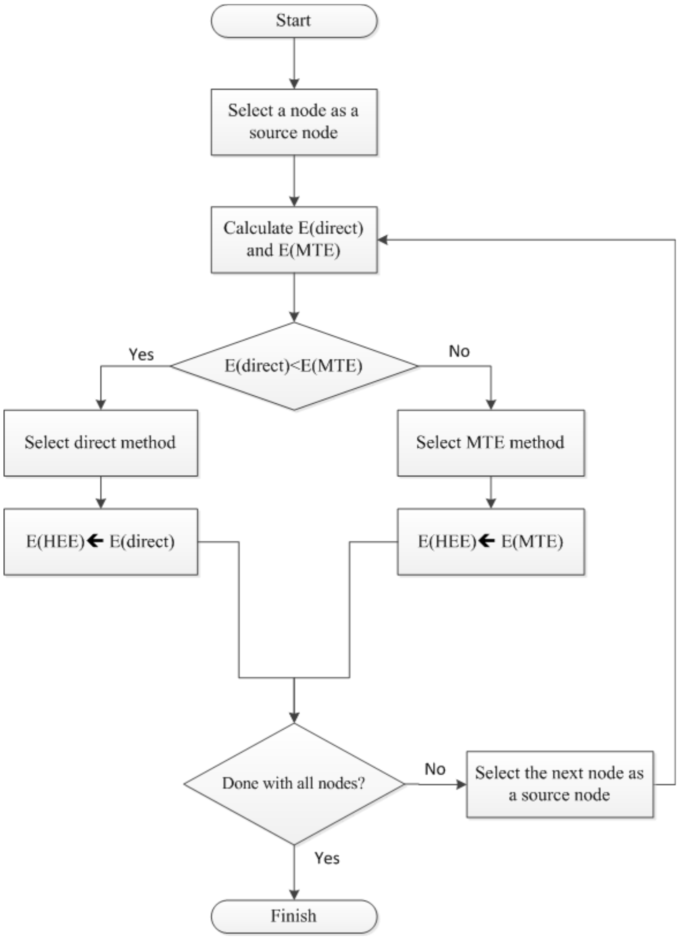

Figure 4: HEE Algorithm

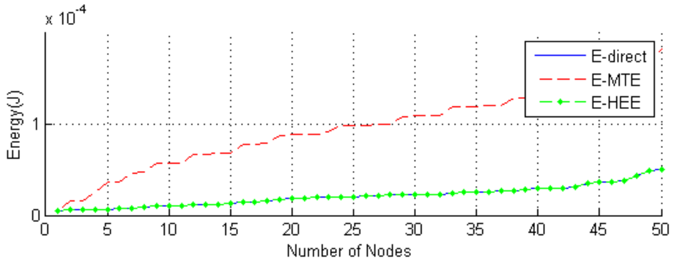

Figure 5: Energy of DT, MTE and HEE for $50m \times 50m$ network size

Table II: Comparision of HEE, DT and MTE for different network size

	Network Size		
	40mx40m	120mx120m	160mx160m
$E_{direct}(J)$	0.0011	0.0056	0.0089
$E_{mte}(J)$	0.0040	0.0055	0.0069
$E_{HEE}(J)$	0.0011	0.0049	0.0061

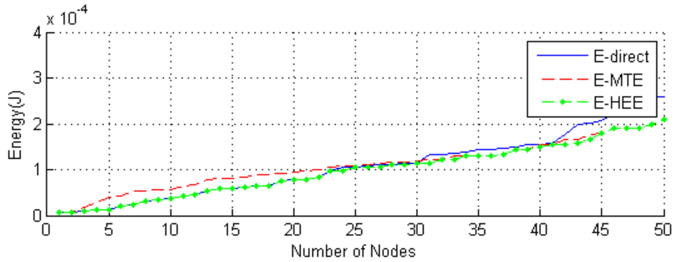

Figure 6: Energy of DT, MTE and HEE for $120m120m$ network size

IV. HEE Versus Direct and MTE

This section discusses the performance of HEE against the DT and MTE. Firstly, the performance of HEE will be assessed for different network size such as: $40m \times 40m$, $120m \times 120m$ and $160m \times 160m$.

The energy dissipation of 50 nodes (for the sake of simplicity and better observation) in $50m \times 50m$ network area is depicted in Figure 5. The consumed energy of all three methods direct, MTE and HEE are presented in blue, red, and green color, respectively. In this figure, the energy of direct method is the same as the HEE and this is the reason that both direct and HEE are shown in by one line. For this network size MTE is not a proper choice since the distances are less than the crossover distance.

In Figure 6 the total energy consumption for $120m \times 120m$ is presented. For some nodes direct transmission performs more efficient and for the rest MTE. Therefore HEE selects the most efficient technique to transmit.

The simulation results for $160m \times 160m$ network size are depicted in Figure 7. In this case, MTE and HEE are almost identical in terms of energy consumption.

In this network the average of distance between nodes is about $19m$, which is not suitable for transmitting data directly to the BS. Then majority of the sensors use MTE algorithm. Therefore, clearly HEE utilizes MTE for transmission of those nodes which are far from gateway.

Table II summarizes the energy dissipation of three methods for different network size. For all the networks HEE consumes less energy than DT and MTE.

Figure 8 illustrates the 3D graph of the total energy of the DT for different network size ($1m$ to $160m$) and message length (1 to $100bits$). As can be seen from the figure, the effect of network size on energy consumption is more than the message length. There is significant increase when the network size is increased from $50m \times 50m$ to $160m \times 160m$ and maximum amount of energy consumption is about $0.0090J$

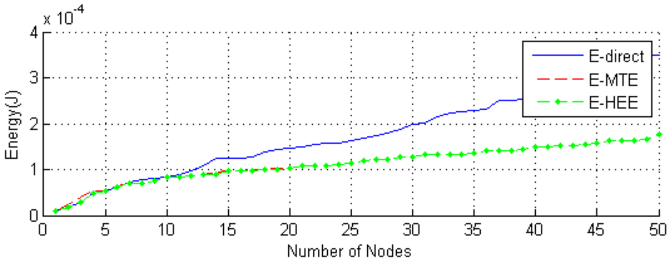

Figure 7: Energy of DT, MTE and HEE for $160m160m$ network size

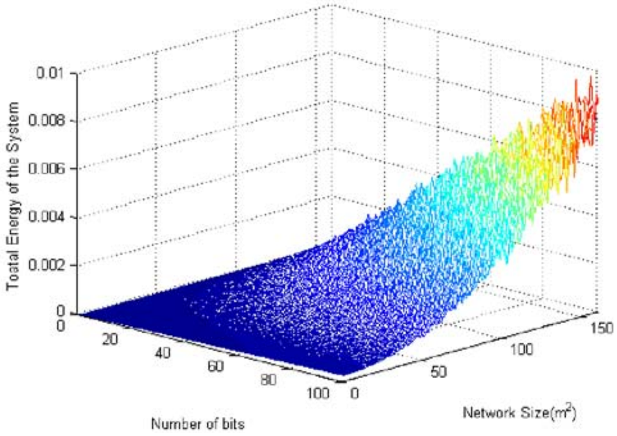

Figure 8: Total energy consumption of DT for different network size and message length

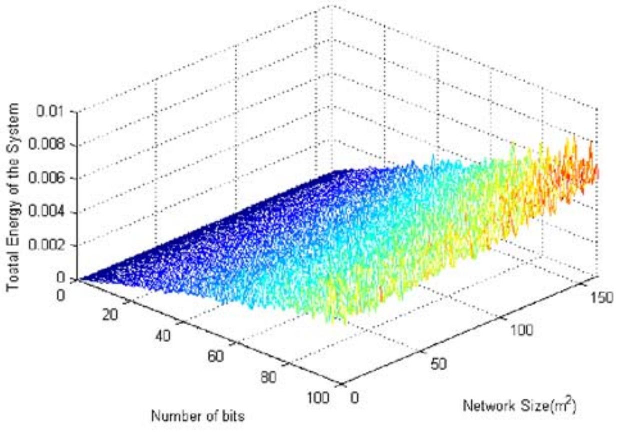

Figure 9: Total energy consumption of MTE for different network size and message length

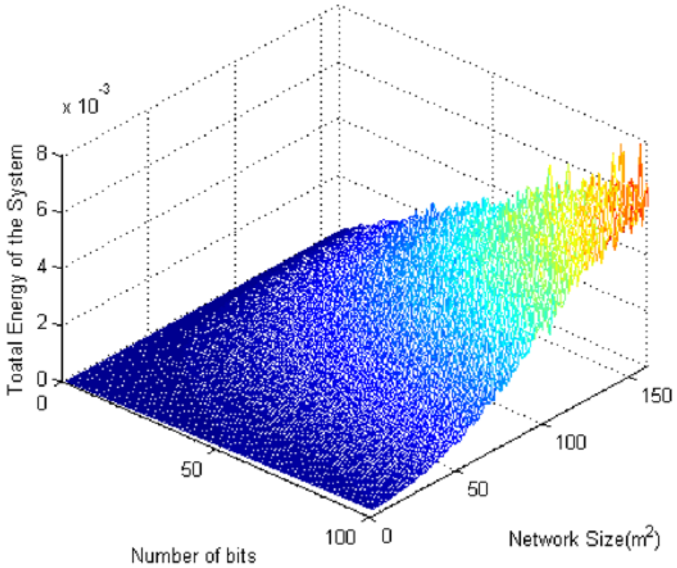

Figure 10: Total energy consumption of HEE for different network size and message length

Table III: Minimum, maximum and Average of energy values

	Min	Max	Average
$E_{direct}(J)$	2.5037e-006	0.0098	0.0018
$E_{mte}(J)$	3.3481e-005	0.0081	0.0026
$E_{HEE}(J)$	2.5037e-006	0.0076	0.0014

Figure 9 shows the total energy of MTE when network size and message length are varying. As can be seen from the figure, the effect of message length on the total energy consumption is more than the network size. Therefore keeping the size of the message as minimum as possible and fixed could result in less energy consumption when using MTE. In addition, the graphs confirm the data in Table I and Table II that there is a considerable amount of rising in the direct method when comparing with MTE.

The energy dissipation of HEE for different network size and message length is given in Figure 10. Comparing three methods, one can say that the maximum energy consumption of HEE is less than the DT and MTE. However, the effect of network size on HEE is more than the message length.

As a result, direct method is more applicable for small sized network and short messages. The MTE is suitable for large scale networks in comparison to direct method and HEE exhibits a better performance for any network size. However it should be mentioned that, the crossover and critical distances must be determined prior to select the method of transmission. Table III summarizes the minimum, maximum and average of energy consumption for three methods. As can be seen, HEE is more energy-efficient comparing the other two methods.

V. CONCLUSIONS

In this paper, a new Hybrid Energy-efficient (HEE) routing protocol for wireless sensor network has been presented. It is the combination of the Direct Transmission and Minimum Energy Transmission which are two simplest routing techniques. Wireless sensor networks are resource constrained since they have limited resources of energy. Therefore, in the proposed method, energy-efficiency has been considered as the main factor. The proposed method (HEE) is applicable for both large and small size networks. The effect of different parameters such message length has been considered as well. However it should be noted that determining a proper routing protocol is highly application-specific and hence several parameters such as crossover and critical distances have to be considered prior to the selection of the routing protocol. Simulation results confirm the efficiency of the proposed method regardless of the network size and message length.

REFERENCES

[1] I. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “A survey on sensor networks,” *Communications Magazine, IEEE*, vol. 40, no. 8, pp. 102–114, Aug.

[2] J. Al-Karaki and A. Kamal, “Routing techniques in wireless sensor networks: a survey,” *Wireless Communications, IEEE*, vol. 11, no. 6, pp. 6–28, Dec.

[3] J. Hao, B. Zhang, and H. Mouftah, “Routing protocols for duty cycled wireless sensor networks: A survey,” *Communications Magazine, IEEE*, vol. 50, no. 12, pp. 116–123, December.

[4] S. Yamunadevi, T. Vairam, C. Kalaiarasan, and G. Vidya, “Efficient comparison of multipath routing protocols in wsn,” in *Computing, Electronics and Electrical Technologies (ICCEET), 2012 International Conference on*, March, pp. 807–811.

[5] D. Goyal and M. Tripathy, “Routing protocols in wireless sensor networks: A survey,” in *Advanced Computing Communication Technologies (ACCT), 2012 Second International Conference on*, Jan., pp. 474–480.

[6] K. Pavai, A. Sivagami, and D. Sridharan, “Study of routing protocols in wireless sensor networks,” in *Advances in Computing, Control, Telecommunication Technologies, 2009. ACT ’09. International Conference on*, Dec., pp. 522–525.

[7] A. Ibrahim, M. Sis, and S. Cakir, “Integrated comparison of energy efficient routing protocols in wireless sensor network: A survey,” in *Business, Engineering and Industrial Applications (ISBEIA), 2011 IEEE Symposium on*, Sept., pp. 237–242.

[8] X.-S. Yi, P.-J. Jiang, X.-W. Wang, and S.-C. Zhang, “Survey of energy-saving protocols in wireless sensor networks,” in *Robot, Vision and Signal Processing (RVSP), 2011 First International Conference on*, Nov., pp. 208–211.

[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, Oct.

[10] W. Heinzelman, “Application-specific protocol architectures for wireless networks,” *PhD Thesis*, 2000.

[11] W. Heinzelman, A. Chandrakasan, and H. Balakrishnan, “Energy-efficient communication protocol for wireless microsensor networks,” in *System Sciences, 2000. Proceedings of the 33rd Annual Hawaii International Conference on*, Jan., pp. 10 pp. vol.2–.

[12] M. Tong and M. Tang, “Leach-b: An improved leach protocol for wireless sensor network,” in *Wireless Communications Networking and Mobile Computing (WiCOM), 2010 6th International Conference on*, Sept., pp. 1–4.

[13] N. Kumar, Sandeep, P. Bhutani, and P. Mishra, “U-leach: A novel routing protocol for heterogeneous wireless sensor networks,” in *Communication, Information Computing Technology (ICCICT), 2012 International Conference on*, Oct., pp. 1–4.

[14] A. Azim and M. Islam, “Hybrid leach: A relay node based low energy adaptive clustering hierarchy for wireless sensor networks,” in *Communications (MICC), 2009 IEEE 9th Malaysia International Conference on*, Dec., pp. 911–916.

[15] M. Farooq, A. Dogar, and G. Shah, “Mr-leach: Multi-hop routing with low energy adaptive clustering hierarchy,” in *Sensor Technologies and Applications (SENSORCOMM), 2010 Fourth International Conference on*, July, pp. 262–268.

[16] M. Sharma and K. Sharma, "An energy efficient extended leach (eee leach)," in *Communication Systems and Network Technologies (CSNT), 2012 International Conference on*, May, pp. 377–382.

[17] A. Yektaparast, F.-H. Nabavi, and A. Sarmast, "An improvement on leach protocol (cell-leach)," in *Advanced Communication Technology (ICACT), 2012 14th International Conference on*, Feb., pp. 992–996.

[18] M. El-Saadawy and E. Shaaban, "Enhancing s-leach security for wireless sensor networks," in *Electro/Information Technology (EIT), 2012 IEEE International Conference on*, May, pp. 1–6.

[19] F. Xiangning and S. Yulin, "Improvement on leach protocol of wireless sensor network," in *Sensor Technologies and Applications, 2007. SensorComm 2007. International Conference on*, Oct., pp. 260–264.

[20] L.-Q. Guo, Y. Xie, C.-H. Yang, and Z.-W. Jing, "Improvement on leach by combining adaptive cluster head election and two-hop transmission," in *Machine Learning and Cybernetics (ICMLC), 2010 International Conference on*, vol. 4, July, pp. 1678–1683.

[21] N. Kumar and J. Kaur, "Improved leach protocol for wireless sensor networks," in *Wireless Communications, Networking and Mobile Computing (WiCOM), 2011 7th International Conference on*, Sept., pp. 1–5.

[22] W. Wang, Q. Wang, W. Luo, M. Sheng, W. Wu, and L. Hao, "Leach-h: An improved routing protocol for collaborative sensing networks," in *Wireless Communications Signal Processing, 2009. WCSP 2009. International Conference on*, Nov., pp. 1–5.

[23] J. Xu, N. Jin, X. Lou, T. Peng, Q. Zhou, and Y. Chen, "Improvement of leach protocol for wsn," in *Fuzzy Systems and Knowledge Discovery (FSKD), 2012 9th International Conference on*, May, pp. 2174–2177.

[24] R. Abrishambaf, S. N. Bayindir, and M. Hashemipour, "Energy analysis of routing protocols in wireless sensor networks for industrial applications," in *Journal of Systems and Control Engineering, Proceeding of Institute of Mechanical Engineers (IMechE)*, May, 2012, pp. 678–684.

[25] T. Rappaport, "Wireless communication: Principles practice," in *Prentice-Hall, Inc., New Jersey*, 1996.