Clustering Algorithm for Improved Network Lifetime of Mobile Wireless Sensor Networks

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***Abstract*—In this paper, we propose LEACH-CCH as a clustering algorithm aimed at improving wireless sensor network lifetime in the case of mobile sensor nodes. LEACH-CCH is a modification of the LEACH algorithm, which was developed for stationary networks. An analysis of energy consumption for the LEACH algorithm is presented to identify which data transmissions are most energy expensive for a node throughout its lifetime. LEACH-CCH reduces the energy expended during the costliest data transmission. By predicting the future positions of sensor nodes and restructuring clusters accordingly, an improvement is seen in overall network lifetime when compared with LEACH.**

I. INTRODUCTION

Wireless sensor networks (WSNs) are collections of low-cost, low-power sensor devices, referred to as nodes, distributed throughout a sensor field. The number of sensor nodes making up a WSN can range from a few hundred to a few thousand. Possible applications include military, agricultural, automotive, space, and environmental concerns making WSNs a topic of large amounts of research over the past few decades. Energy limitations persist due to the interest in minimizing the cost and physical footprint associated with the individual sensor nodes. As a direct consequence of the limited energy characteristics of the sensor nodes that comprise WSNs, the major challenges in this field relate to communication, data storage, and computational capability. Communication methods are necessary to allow data transmission between nodes and to ultimately transmit data collected by sensor nodes to a centralized receiver, known as a base station. A common method of decreasing overall energy consumption is through hierarchical communication routing methods known as clustering. Clustering protocols are characterized by dividing the network into subsections or 'clusters' of fixed or varying numbers of nodes. Data is transmitted from the sensor nodes within a cluster to the base station through an elected cluster-head (CH). Cluster-head responsibilities are usually divided equally among sensor nodes, electing a new cluster-head after each successful data packet transmission, which is referred to as a round. In [1] a pioneering hierarchical cluster protocol known as the Low-Energy Adaptive Clustering Hierarchy (LEACH) is introduced. The LEACH protocol achieved a drastic improvement in overall network lifetime by as much as a factor of eight, when compared to the conventional direct transmission communication and minimum-transmission-energy (MTE) protocols common at the time. Node decay is also seen to occur more uniformly allowing for a more even distribution of sensors throughout the life of the sensor network. Since the development of the LEACH protocol, numerous advances have been made, further improving upon its performance, with a large focus on cluster-head selection algorithms [2]. The majority of related WSN research has been focused on stationary sensor nodes. However, in some applications the sensor nodes will not be stationary. In this case, common protocols such as LEACH, see a significant breakdown in performance. In [3] LEACH-Mobile is introduced as a variation of the LEACH protocol in which considerations are made to better accommodate sensor node movement. One key assumption with LEACH is that any node has the capability to transmit its data directly to the base station. In many applications the sensor nodes will not have this capability. LEACH-Mobile is mainly focused on improving network performance, when this assumption is not valid. In this case a large amount of data is lost when nodes move out of range of their cluster-heads. LEACH-Mobile's primary focus is on restructuring node clusters once sensor nodes move out of range during LEACH's steady-state phase. In [3] and [4] it is shown that LEACH-Mobile is an improvement over LEACH when loss of data is considered. However, it is also shown that energy consumption worsened significantly in LEACH-Mobile due to the increased messaging required to reform node clusters. In [5], the mobility of the cluster-head is considered in the cluster-head election process to further improve upon the performance of LEACH-Mobile. It is shown that the enhancement improves data transmission by as much as 18% but at the cost of increased computational overhead and energy consumption. This work proposes LEACH-CCH (LEACH – Centered Cluster-head), which is a modified LEACH protocol, directed at improving network lifetime when sensor nodes are mobile.

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II. LEACH-CCH Cluster Routing Protocol

A. LEACH Cluster Routing Protocol Overview and Analysis

LEACH forms the basis for LEACH-CCH. LEACH's operation is broken up into rounds, which consist of a set-up phase, in which clusters are formed and a steady-state phase in which data transmission to the base station occurs. At the beginning of the set-up phase, each node determines whether or not to become a cluster-head. This decision is probabilistic and based on the number of rounds since the last time the node was a cluster-head, as well as a predetermined percentage of nodes that should become cluster-heads. Once cluster-heads have been self-nominated, they broadcast an advertisement message to all nodes within the network. Non-cluster-head nodes decide which cluster to join based on the received signal strength of the message. Once this decision is made the non-cluster-head nodes transmit messages to the cluster-head of their choice informing of their decision to join the cluster. Once the cluster is formed, the cluster-head creates and broadcasts a TDMA schedule to the member nodes, which determines when each node will transmit its data during the steady-state phase. The steady-state phase begins with each non-cluster-head node transmitting its data to the cluster-head at its scheduled time. Once every non-cluster-head node has had a chance to transmit, the cluster-head performs signal processing functions on the data to compress it. The cluster-head then transmits the compressed data to the base station. After this, the round is concluded and the process begins again with a new round. LEACH is well suited for the case in which nodes are stationary, but when nodes are moving the performance of LEACH is significantly reduced in terms of network lifetime. Recognizing that LEACH was not intended for such operation, we were interested in the possibility that a few slight modifications could increase the performance to more acceptable levels. LEACH was simulated, as described in section III.B, in part to observe which data transmissions were most costly when sensor nodes were mobile. Simulations indicated throughout the network lifetime, 72% of a node's available energy is spent transmitting while 28% is consumed receiving transmissions. The most expensive transmission occurs during the steady-state phase, when a node is transmitting data to its cluster-head, as shown in Table I. This transmission accounts for 69% of a single node's available energy throughout the network lifetime. This is a significant increase when compared to 57% in the case of stationary sensor nodes. One might anticipate that the majority of a node's energy would be consumed when transmitting to the base station during its rounds as cluster-head; however, a node is only going to be cluster-head for approximately 5% of the rounds during its lifetime, but it will be transmitting data to its cluster-head for the remaining 95%.

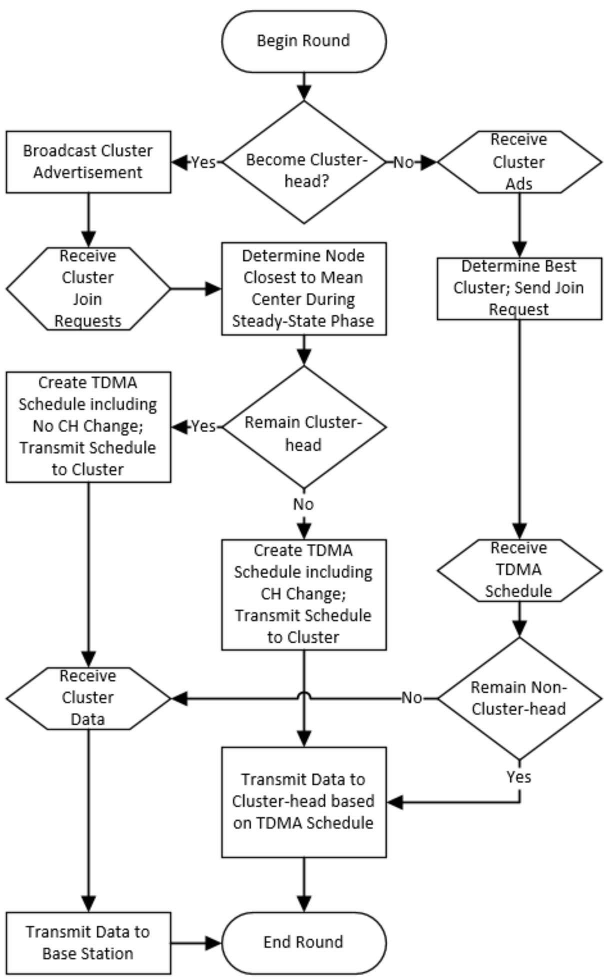

Fig. 1. Flowchart detailing a round of the LEACH-CCH algorithm.

TABLE I
COMPARISON OF TRANSMISSION ENERGIES FOR LEACH WITH STATIONARY AND MOBILE SENSOR NODES

Message	Stationary	Mobile
Cluster-head Ad	6%	4%
Cluster Join Request	14%	9%
TDMA Schedule	2%	1%
Data to Cluster-head	57%	69%
Data to Base Station	21%	17%

B. LEACH-CCH Cluster Routing Protocol

The motivation for LEACH-CCH is to improve the network lifetime of LEACH in the case of mobile sensor nodes. A flowchart providing a high-level view of a LEACH-CCH round is given in Fig. 1. When nodes are moving, the major cause of degraded performance is because the clusters formed during the set-up phase will break apart throughout the steady-state phase of a round as nodes move away from one another, as illustrated in Fig. 2, Fig. 3, and Fig. 4. This breakdown of clusters increases the energy expended by the non-cluster-head nodes by increasing the distance each node must transmit to reach its elected cluster-head. LEACH-CCH makes a modification to the LEACH protocol during the set-up phase of a round aimed at

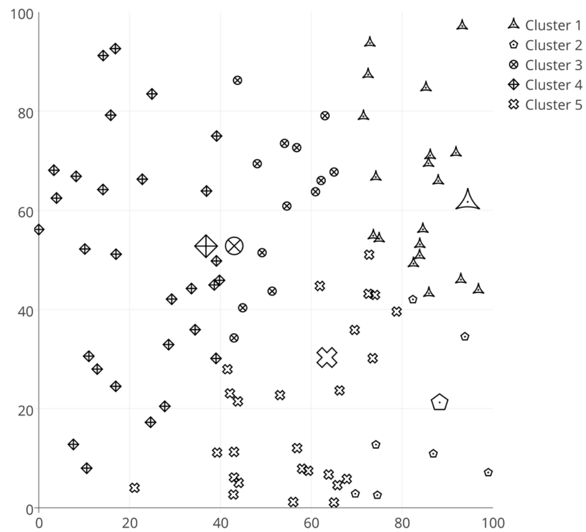

Fig. 2. Mobile sensor node clusters at the beginning of the LEACH steady-state phase at time *t.* (Larger icons indicate cluster-heads)

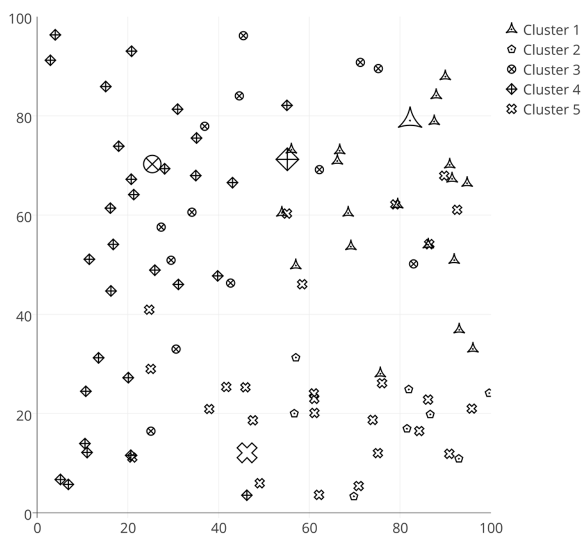

Fig. 4. Mobile sensor node clusters during the LEACH steady-state phase at time *t + 10.*

reducing the effect of this cluster decay. During the set-up phase of LEACH, cluster-heads are self-elected based on a probabilistic calculation, which is a function of the number of rounds since the node was a cluster-head as well as a predetermined percentage of nodes that should become cluster-heads, as detailed in [1]. Each cluster-head, then transmits an advertisement message to all nodes within the network. Non-cluster-head nodes receive this message and select the nearest cluster-head based on the signal strength of the advertisement message. Each non-cluster-head node then transmits a cluster-head selection message indicating its decision to join the cluster. LEACH-CCH assumes this selection message also contains information including the non-cluster-head node's

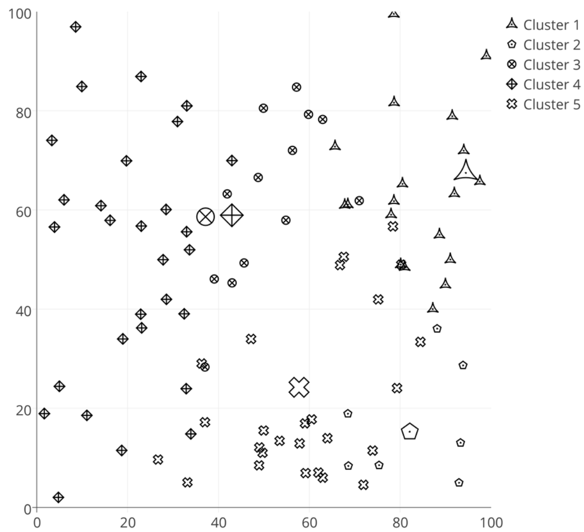

Fig. 3. Mobile sensor node clusters during the LEACH steady-state phase at time *t + 5.*

current velocity and position. At this point, clusters have been formed as shown in the network depicted in Fig. 5. In LEACH-CCH, a restructuring of the clusters is conducted at this point, as detailed in Algorithm 1, in which a new cluster-head is selected based on which node is nearest to the center of the cluster, as shown in Fig. 6. This reduces the distance between the majority of the nodes in the cluster and the cluster-head, which reduces the energy expended during data transmission to the cluster-head. As nodes move during the steady-state phase, the center of the cluster will also move. This makes it beneficial to predict the location of nodes throughout this phase of the round. Assuming the position and velocity of nodes are known by the cluster-head during the formation of clusters and also assuming velocity is constant. The cluster-head can determine where each node will be at different times in the steady-

Algorithm 1 LEACH-CCH Cluster Restructuring

for timesteps i to t_{ss}
  calculate cluster center of mass, R
  for each node in cluster, n_i
    n_i movement advanced i time steps
    centerDistances_n_i += n_i distance to R
  end loop
end loop
let bestDistance = current CH's distance to R
let bestNode = current CH
for each node in cluster, n_i
  avgCenterDistance = centerDistances_n_i/t_{ss}
  if avgCenterDistance < bestDistance
    bestNode = n_i
    bestDistance = avgCenterDistance
  end if
end loop

New cluster-head ≡ bestNode

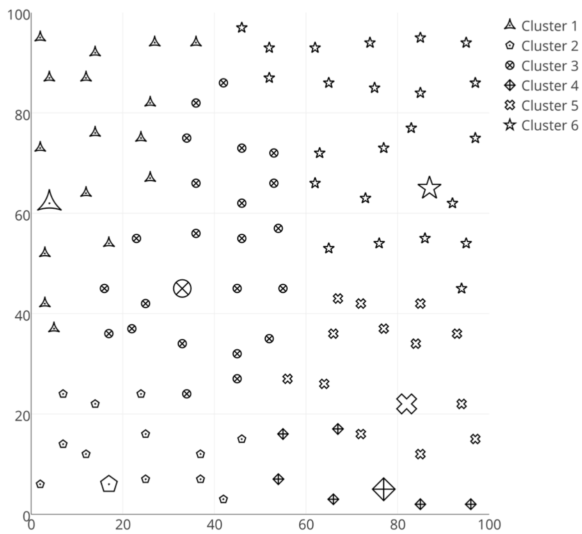

Fig. 5. LEACH-CCH sensor node clusters before restructuring. (Larger icons indicate cluster-heads).

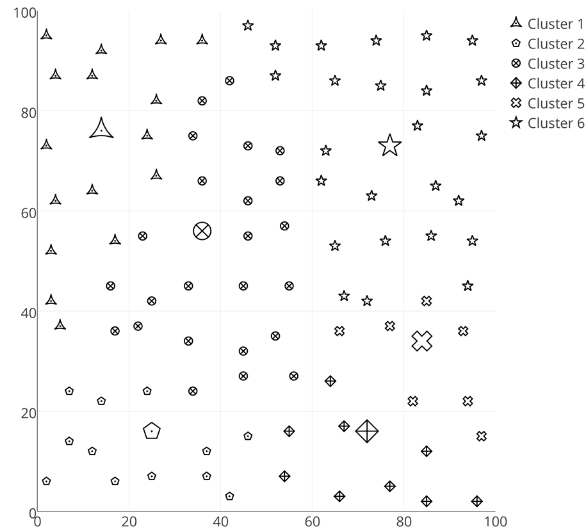

Fig. 6. LEACH-CCH sensor node clusters after restructuring.

state phase. Before transmitting the TDMA schedule, the cluster-head determines the number of time steps required for all cluster nodes to transmit their data to the cluster-head, t_{ss}, and steps forward in time to determine the position of each node throughout the steady-state phase. At each time step, the cluster-head calculates the center of mass of the cluster and records each node's distance from the center until the final time step is reached. The mean of these distances is taken, and the node with the shortest average distance becomes the new cluster-head. LEACH-CCH makes no consideration for the number of times a node has been selected as the replacement cluster-head, meaning a node could potentially become the replacement cluster-head multiple rounds in a row. When simulating LEACH-CCH, modifications were made to limit the number of rounds a node could become replacement cluster-head, but it was observed that the network lifetime was best when this consideration what not made. Often times the original cluster-head is the best candidate, and in this situation the original node remains the cluster-head. In the event of a tie for replacement cluster-head, a random selection is made between the two.

III. Simulation and Analysis

A. First Order Radio Model

As in [1], the first order radio model was used for simulation of LEACH-CCH. The model assumes $E_{elec} = 50$ nJ/bit for the energy consumption of the transmitter and receiver electronics and $\epsilon_{amp} = 100$ pJ/bit/m^2 for the transmission amplifier. During signal transmission of a k-bit message at distance d, assuming an r^2 energy loss, the radio dissipates:

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

$$E_{Tx}(k,d) = E_{elec} * k + \epsilon_{amp} * k * d^2 \qquad (1)$$

To receive a message, the radio would dissipate:

$$E_{Rx}(k,d) = E_{Rx-elec}(k)$$
$$E_{Rx}(k,d) = E_{elec} * k \qquad (2)$$

When nodes are mobile, equation 1 should be modified to consider the future transmission distance, $d_{st}(t) = |n_s(t) - n_t(t)|$, in which $n_t(t)$ is the location of the target node and $n_s(t)$ is the location of the source node at time *t*. Equation 1 then becomes:

$$E_{Tx}(k,t) = E_{elec} * k + \epsilon_{amp} * k * d_{st}(t)^2 \qquad (3)$$

B. LEACH-CCH Protocol Simulation

A discrete-time event simulator was developed in Python using SimPy. LEACH and LEACH-CCH were simulated for comparison of energy consumption. The field size was 100m x 100m, and the sensor network consisted of 100 nodes randomly distributed, each with initial energy of 0.5J. The base station was located at (x = 50, y = 150). Messages were categorized as data messages or control messages consisting of 2000 and 500 bits respectively. Control messages are used to organize the clusters during the setup phase. Data messages are the packets transmitted by non-cluster-head nodes to the cluster-heads, as well as the compressed data sent from the cluster-heads to the base station. Initially simulations of stationary nodes were conducted. It was anticipated that LEACH-CCH would perform a least slightly more efficiently than LEACH in the stationary case due to the restructuring of clusters selecting the node closest to the center of the cluster as the new cluster-head. Simulations supported this assumption as shown in Fig. 7, where LEACH-CCH

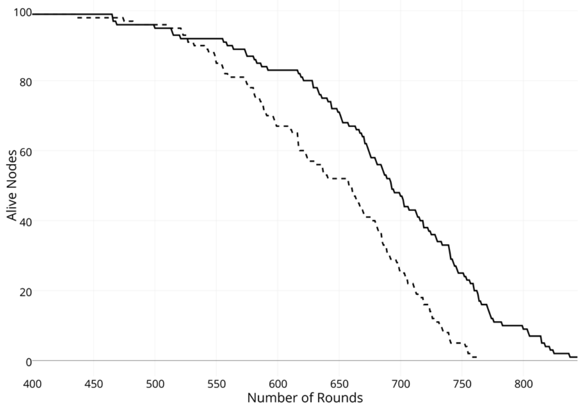

Fig. 7. Network lifetime comparison of LEACH (Dashed line) and LEACH-CCH (Solid line) in a stationary sensor node scenario.

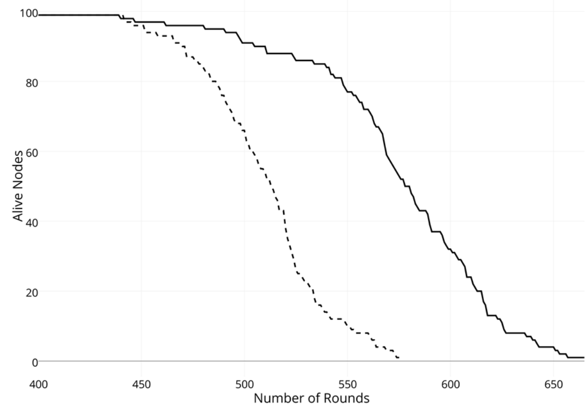

Fig. 8. Network lifetime comparison of LEACH (Dashed line) and LEACH-CCH (Solid line) in a mobile sensor node scenario.

TABLE II
TRANSMIT ENERGY FOR STATIONARY SENSOR NODES

Message	LEACH	LEACH-CCH
Cluster-head Ad	19.4mJ 0.546mJ/Msg	25.8mJ 0.608mJ/Msg
Cluster Join Request	44.6mJ 0.073mJ/Msg	60.2mJ 0.086mJ/Msg
TDMA Schedule	4.47mJ 0.127mJ/Msg	4.10mJ 0.100mJ/Msg
Data to Cluster-head	178mJ 0.291mJ/Msg	174mJ 0.247mJ/Msg
Data to Base Station	87.5mJ 2.458mJ/Msg	83.5mJ 1.969mJ/Msg

TABLE III
TRANSMIT ENERGY FOR MOBILE SENSOR NODES

Message	LEACH	LEACH-CCH
Cluster-head Ad	15.55mJ 0.579mJ/Msg	18.35mJ 0.583mJ/Msg
Cluster Join Request	35.02mJ 0.076mJ/Msg	38.29mJ 0.073mJ/Msg
TDMA Schedule	3.250mJ 0.129mJ/Msg	4.181mJ 0.137mJ/Msg
Data to Cluster-head	252.3mJ 0.530mJ/Msg	201.2mJ 0.374mJ/Msg
Data to Base Station	63.80mJ 2.361mJ/Msg	74.73mJ 2.437mJ/Msg

maintained 80% of alive nodes for 8.2% longer than LEACH. A breakdown of a single node's energy consumption for LEACH and LEACH-CCH as observed during simulation with stationary sensor nodes is given in Table II. It can be observed from Table II that LEACH-CCH achieves an improvement of 0.44mJ per data message transmitted to the cluster-head. For simulation of the mobile node scenario each node was given a different random velocity from 2.8 to 3.2 m/s. When a node meets the field boundary it bounces off by inverting the direction of the axis of contact, in a 'pong-like' fashion. The results are shown in Fig. 8. It can be observed that LEACH-CCH achieves a 13% improvement over LEACH, maintaining 80% of alive nodes for 548 rounds compared to LEACH's 484 rounds. A breakdown of a single node's energy consumption for LEACH and LEACH-CCH as observed during simulation with mobile sensor nodes is given in Table III. It can be observed from Table III that LEACH-CCH achieves an improvement of 0.156mJ per data message transmitted to the cluster-head.

IV. CONCLUSION AND FUTURE WORK

It has been demonstrated that LEACH-CCH achieves improved network lifetime over LEACH in both cases of stationary and mobile sensor nodes. LEACH-CCH achieves this improvement by restructuring sensor node clusters before the beginning of the steady-state phase. By reselecting cluster-heads based on which node is closest on average to the center of the cluster, the distances non-cluster-head nodes must transmit their data are improved. Future work will consider forming clusters based on predicting future node movement to minimize cluster decay throughout the steady-state phase of the round. Future work will also observe the scenario in which cluster decay becomes more of an issue when radio transmission capability is limited, in which case a node can travel out of range of its cluster-head resulting in a loss of data.

REFERENCES

[1] W. R. 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*, 2000.

[2] L. M. C. Arboleda and N. Nasser, "Comparison of Clustering Algorithms and Protocols for Wireless Sensor Networks," *2006 Canadian Conference on Electrical and Computer Engineering*, Ottawa, Ont., 2006, pp. 1787-1792.

[3] Y. Chung and D. Kim, "Self-Organization Routing Protocol Supporting Mobile Nodes for Wireless Sensor Network," in *First International Multi-Symposiums on Computer and Computational Sciences*, 2006.

[4] G. Renugadevi and M. G. Sumithra, "An Analysis on LEACH-Mobile Protocol for Mobile Wireless Sensor Networks," in *International Journal of Computer Applications*, 2013.

[5] G. S. Kumar, P. M. V. Vinu and K. P. Jacob, "Mobility Metric based LEACH-Mobile Protocol," *Advanced Computing and Communications, 2008. ADCOM 2008. 16th International Conference on*, Chennai, 2008, pp. 248-253.