Mobility Metric based LEACH-Mobile Protocol

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***Abstract*—Cluster based protocols like LEACH were found best suited for routing in wireless sensor networks. In mobility centric environments some improvements were suggested in the basic scheme. LEACH-Mobile is one such protocol. The basic LEACH protocol is improved in the mobile scenario by ensuring whether a sensor node is able to communicate with its cluster head. Since all the nodes, including cluster head is moving it will be better to elect a node as cluster head which is having less mobility related to its neighbours. In this paper, LEACH-Mobile protocol has been enhanced based on a mobility metric "remoteness" for cluster head election. This ensures high success rate in data transfer between the cluster head and the collector nodes even though nodes are moving. We have simulated and compared our LEACH-Mobile-Enhanced protocol with LEACH-Mobile. Results show that inclusion of neighbouring node information improves the routing protocol.**

I. Introduction

Wireless sensor networks [1][2] are promising unprecedented levels of access to information about the physical world, in real time. Many areas of human activity are starting to see the benefits of utilizing sensor networks. Some of the real deployments include UC Berkley's Smart Dust, MIT's μ-Adaptive Multi-domain Power aware Sensors and UCLA's Wireless Integrated Sensor Networks. In almost all such cases, sensor networks are statically deployed. In static networks, the mobility of sensors, users and the monitored phenomenon is totally ignored. The next evolutionary step for sensor networks is to handle mobility in all its forms. One motivating example could be a network of environmental monitoring sensors, mounted on vehicles used to monitor current pollution levels in a city. In this example, the sensors are moving, the sensed phenomenon is moving and the users of the network move as well.

The dynamic nature of mobile wireless sensor networks introduces unique challenges in aspects like data management, accuracy and precision, coverage, routing protocols, security and software support. Many of the above mentioned challenges related to a static deployment of the sensors are well addressed by the researchers. One of the most important constrains on sensor nodes is the route enabling when the nodes keep moving. It has been reported that the clustering mechanisms and hierarchical routing make huge improvement in sensor networks in terms of energy consumption and efficient data gathering. Such improvement is due to the structure of the network, assumed before the deployment of the sensor nodes. Once the network becomes dynamic we do not have the freedom to pre-assume such structures. The conventional routing protocols for static sensor networks are to be optimized once mobility is introduced. To study the performance of routing protocols under such conditions, we have to consider the mobility patterns and associated mobility metrics.

In this paper we propose an improvement to the LEACH-M protocol, which is suitable for mobile wireless sensor networks. The basic idea of this LEACH-Mobile-Enhanced (LEACH-ME) protocol is to make sure as much as possible that the cluster heads are from the group of mobile nodes having minimum node mobility or they are in a group motion with the other cluster members (as in RPGM model [3]). By doing the modified election process for cluster heads or modified rotation of duty of cluster heads, the protocol makes sure that the clusters are disturbed minimally in the event of movement of cluster heads.

II. Related Work

This section briefly outlines the related work in mobile sensor network (MSN) and LEACH protocol improvements.

A. Mobile Sensor Network (MSN) Research

Researchers have only recently started to study the sensor movement and unique attributes of mobile sensor networks since the sensor networks were originally assumed to consist of only static nodes. It has been suggested [4] that the mobility of sensor nodes improves the sensing coverage. Robotic Fleas project in Berkeley [5], Robomote [6] and Parasitic Mobility [7] were attempts to enable mobility in sensor networks. It is shown that 'data mule' [8] approach can be used to efficiently collect the data by minimizing the data delivery latency with minimum energy consumption in a controlled mobile sensor network. A number of approaches exploiting mobility for data collection can be found in [9]. Adaptive Sampling and Prediction (ASAP) [10] is a real world application of MSN where a fleet of undersea mobile sensor nodes coordinate and collect measurements of ocean without human intervention. A sensor network based adaptive navigation system is discussed in [11]; where sensors equipped on vehicles collect real-time traffic information and exchanges among the neighbour vehicles.

Muneeb Ali et al [12] discuss a mobility management service layer in SensorNet Protocol which is a cross layer approach where mobility information is stored in a database so that it is visible across all layers. A new concept called network dynamics is introduced in [13] to solve mobility management issues. This work is an earlier attempt to formulate laws that govern mobility motivated by classical dynamics that study the movement of objects. In short, mobility of sensor nodes is of great importance and there is an uprising research trend towards leveraging node mobility to enhance network performance in terms of energy efficiency, coverage, lifetime, localization and fault tolerance.

B. LEACH Protocol enhancements

Low Energy Adaptive Clustering Hierarchy (LEACH) [14], is one of the most popular hierarchical routing protocols for wireless sensor networks. The idea is to form clusters of the sensor nodes based on received signal strength indicator (RSSI) and use local cluster heads as routers to the sink. LEACH has motivated the design of several other protocols which try to improve upon the cluster-head selection process [15][16].

LEACH protocol does not consider the mobility of sensor nodes. In mobility centric environments an agent based data collection scheme is put forward in [17]; where a mobile agent effectively process the data and saves the total energy spent by the network. LIMOC [18] is a scheme to enhance the life time of network in which energy rich moving cluster heads collaborate intelligently each other to route the data to the base station. The Enhancement to LEACH to support mobility is introduced as LEACH-Mobile, in short “LEACH-M” [19]. The basic idea in LEACH-M is to confirm whether a mobile sensor node is able to communicate with a specific cluster head.

III. LEACH MOBILE ENHANCED PROTOCOL

We adopt the proposals in the LEACH-M protocol and extend it by proposing remoteness concept for cluster head election. This section explains the cluster head election and maintenance of both LEACH-M and LEACH-ME protocols.

A. LEACH Routing Phases

The LEACH operations are mainly in two major phases - Set-up phase and Steady-state phase. Set-up phase is the initial one and this is the phase where all cluster formation takes place. This phase is relatively short compared to the steady-state phase. In this phase, one of the basic ideas in LEACH-ME is to confirm the election of specific cluster heads which either have no node movement or minimum relative node movement.

In the steady-state phase, the cluster head and non-cluster head nodes receive a particular message at a given time slot according to TDMA time schedule of sensor cluster, and then reorganize the cluster with minimum energy consumption. The steady state phase does the actual data transfer between the sensing node and the sink.

B. Cluster Head Election and Maintenance in LEACH-M

LEACH-M uses the same set-up procedure used in the basic LEACH protocol. In LEACH, the nodes organize themselves into local clusters, with one node acting as the local base station or *cluster-head*. If the cluster heads are chosen a priori and fixed throughout the system lifetime, as in conventional clustering algorithms, it is easy to see that these sensors chosen to be cluster-heads would die quickly due to overloading, ending the useful lifetime of all nodes belonging to those clusters. Thus LEACH includes randomized rotation of the high-energy cluster-head position such that it rotates among the various sensors in order not to drain the battery of a single sensor. In addition, LEACH performs local data fusion to “compress” the amount of data being sent from the clusters to the base station, further reducing energy dissipation and enhancing system lifetime.

Sensors elect themselves to be local cluster-heads at any given time with a certain probability. These cluster head nodes broadcast their status to other sensors in the network. Each sensor node determines to which cluster it wants to belong by choosing the cluster-head that requires the minimum communication energy. Once all the nodes are organized into clusters, each cluster-head creates a schedule for the nodes in its cluster. This allows the radio components of each non-cluster-head node to be turned off at all times except during its transmit time, thus minimizing the energy dissipated in the individual sensors.

C. Cluster Head Election and Maintenance in LEACH-ME

In LEACH the election and cluster head rotation makes sure that the cluster heads do not die due to prolonged extra work. This is done by the random rotation of the cluster head duty across the nodes in the cluster by considering the energy level of the nodes. In view of mobility centric environment, the election of a cluster or the job rotation of the cluster head on purely energy level, without considering the node mobility can cause serious problem. A node with sufficiently rich energy level, taking over the duty of cluster head possessing high mobility, may move out of the cluster, causing the cluster to become headless. The situation causes the cluster to go for a new cluster head. But again the mobility of the nodes is not considered causing the same process to repeat.

To cope with the situation of cluster head going out of reach due to mobility, the head rotation process needs to consider the node’s mobility. The nodes need to maintain certain additional information to make room for handling mobility. Following are some of the information the node should maintain [20]:

- *Role*: to indicate if the sensor is acting as a Cluster head CH (value=1) or as a participating node (value=0) in the zone
- *Mobility Factor*: calculated based on the number of times a node changes from one cluster to another or on the basis of remoteness.
- *Members List*: if the node is a cluster head, a list which contains references to the nodes associated with its Cluster.
- *TDMA Schedule*: Time slot information, when data need to be collected from the sensor nodes by the cluster head.

The node needs to maintain all these four information, in which the mobility factor is the one with prime importance for the election of cluster head. There are different approaches to calculate mobility factor. One approach is to calculate the transitions the node makes across the cluster and the other one is through the concept of remoteness introduced in [21]. In our proposed scheme we primarily focus on the second method for the cluster head election.

1) Mobility factor based on transition count

The node associated to a cluster in motion may break its association to the cluster head and create a new association with a new cluster head in its new territory. The mobility factor is calculated based on the number of times the node moves from one cluster to another.

2) Mobility factor through the Concept of Remoteness

Mobility measure should have a linear relationship with link change rate. If all the nodes in the cluster are in group motion like in RPGM, even though the nodes are in motion, the average link change is minimal, maintaining high spatial dependency. The node movement in such scenarios does not make any breakage of association with the cluster head. So remoteness can be treated as a measure of mobility factor.

Let $n_i(t), i = 0,1,2,3,...N-1$, where N is the number of nodes, represents the location vector of node *i* at time *t* and $d_{ij}(t) = |n_j(t) - n_i(t)|$, the distance from node *i* to *j* at time *t*. Then the remoteness from node *i* to node *j* at time *t* is $R_{ij}(t) = F(d_{ij}(t))$, where F is the function of remoteness. For a simple choice of F as identity function, the remoteness is just the distance between the nodes.

As a node moves relative to the other nodes, remoteness remains proportionate to its previous values. But as the node moves in a manner, in which its speed and angular deviation from the current state are not predictable, remoteness changes in time. Thus the definition of relative mobility measure in terms of remoteness of a node as a function of time with respect to its immediate neighbors is

$$M_i(t) = \frac{1}{N-1}\sum_{j=0}^{N-1} |d'_{ij}(t)| \qquad (1)$$

In order to calculate $d_{ij}(t)$, from i^{th} node to all its j^{th} neighboring nodes, the broadcast medium may be used. In LEACH protocol all nodes in a cluster are time synchronized with the cluster head. The TDMA schedule issued by the cluster head are complied by the nodes. Each node uses its time slot given by the schedule to communicate to the cluster head. To reduce energy consumption during the other time slots not intended for a node, the node goes to sleep mode. Therefore even though a node is in the radio range of its neighboring nodes, it can not hear the information sent by its immediate neighbors. In order for nodes to hear simultaneously, the cluster head gives an extra time slot as shown in Figure 1.

During the period of extra time slot, called ACTIVE slot, all nodes need to send their broadcast IDs. As all nodes are time synchronized with cluster head and use radio propagation, the node *i* can make use of the ID broadcast of all the nodes it hears and calculate $d_{ij}(t)$.

Slot 0	Slot 1	Slot 2	……	Slot N-1	ACTIVE

Figure.1 TDMA time slots in LEACH-ME protocol

Let beacon sent by a neighboring node was at the start of ACTIVE time slot t_1 and received at time t_2. The distance $d_{ij}(t)$ = Radio velocity * $|t_2-t_1|$.

Upon receiving the information from all the nodes, it's possible to calculate the mobility factor for N neighbors through equation (1). The node with least mobility factor is considered for the next cluster head, provided the energy level of that node is not below the threshold. Also the transition count for the node is checked to be minimal among all of its neighbors.

The method is explained in steps as given below. We denote {a} as the normal node, *c* as the cluster head. The following steps illustrate cluster head election process.

1. Cluster head c sends ACTIVE message to all its cluster members to wake up simultaneously.
   ACTIVE: *c* → {a}: wake up
2. Upon receiving the ACTIVE message, all cluster members broadcast their IDs with time-stamp. All cluster member nodes set time-out to receive broadcast of their entire neighboring node IDs. The ID_broadcast helps individual node to know its neighbors.
   ID_broadcast: {a}→ NEIGHBORS*:* know_neighbors
3. Once the broadcast ID timer expires, each node calculates the remoteness based on the IDs received and the time at which the IDs are received. The calculated remoteness information is broadcast by each node. The process helps to know the remoteness of neighbors of each other.
   remoteness:{a}→NEIGHBORS: know_remoteness
4. Once all the remoteness values of neighbors are received nodes can go for cluster head election, where the node with minimal mobility factor is elected as cluster head, provided its energy level is not below the threshold.

Initial creation of clusters is based on certain random selection. The number of cluster heads is based on a suggested percentage of cluster heads for the network. Normal figure is 5% of the total number of nodes. In view of mobility, the figure can go high depending on the spatial dependency factor and the speed with which the node moves. A probable figure is of the order of 5 -15 % of the total number of nodes.

It should be noted that the cluster head election need not be done at every TDMA time slot. ACTIVE time slot can be introduced periodically after a certain number of regular TDMA periods. The periodicity can be decided based on the active mobility of the nodes.

D. ACTIVE slot deciding phase

Calling ACTIVE slot in regular basis without considering the nature of the mobility of the nodes can cause extra loss of energy to the nodes and hence cause threat to the life of nodes. So the selection of periodicity of ACTIVE slot in TDMA schedule should be flexible based on the mobility nature of the nodes. It is desirable to have a measure to decide the periodicity of the ACTIVE slot. The approach followed is the transition count as measure to periodicity decision. For a specific cluster the average transition count of members decide the slot frequency.

The node which migrates from one cluster to the other cluster during steady state phase need to have a count of number of number of such transition it made. The concept is stated earlier as mobility factor based on transition count.

In order to have the average transition count of the cluster there should be certain information with the cluster head regarding the individual transition count of the node members. But there is no additional time slot available to communicate the transition count of the nodes to the cluster head. To resolve this, each node get a data request from the cluster head need to sent back data along with transition count information to the cluster head. Cluster head need to process the transition count information separately. The decision of including ACTIVE slot in the next TDMA cycle is taken based on the average transition count calculated for the last few cycles. Transition count beyond the threshold decides the ACTIVE slot induction.

The method explained is put in steps as given below.

1. Cluster head sends data request to the respective nodes in their TDMA time slot. If the TDMA cycle does not contain ACTIVE slot, then the data request is sent with the active flag as zero.
   REQ_Data/active = 0: $c \rightarrow \{a\}$: get data
2. Upon receiving the data request from cluster head, the cluster member sent its data along with transition count for the last few cycles to the cluster head.
   DATA: $\{a\} \rightarrow c$: sent data and transition count
3. Once all the cluster member data available, the cluster head calculate the average transition count for the last few cycles and decide whether it is above the threshold decided earlier. If the value is above the threshold, then all the cluster members are intimated about the inclusion of ACTIVE slot in the next TDMA cycle by setting active flag in the REQ_Data
   REQ_Data/active=1: $c \rightarrow \{a\}$: get data and reschedule
4. Upon receiving the data request with active flag set, the cluster members need to reschedule the TDMA time slot accordingly to include the ACTIVE frame.

E. Steady State phase in LEACH-ME

In the set-up phase of LEACH, the clusters are organized and cluster heads are elected. Configuration formed in the set-up phase is used to transfer monitored data to the base station during the steady state phase. Because of that, it can not accommodate the alteration of cluster by mobile sensor nodes during the steady-state phase. It is possible to resolve this problem by a simple and traditional method that adds membership declaration of mobile nodes to typical LEACH protocol. In LEACH-M scheme, the non-cluster head nodes instead of sending the data to the cluster head in their allotted time slot in the TDMA schedule wait for a request (REQ_Data) from the cluster head to send data.

In the vicinity of mobility it may happen that the REQ_Data sent to a particular node by the cluster head is not received by the node, since it is moved to a new location which is not in the radio range of its current cluster head. After sending the REQ_Data, if no response is obtained from the node before the time slot allotted for that node, the node will be marked as mobile-suspect. If the same thing repeats for the next time slot allotted for the same node, then the suspect node is declared as mobile and the time slot for that node is deleted from the TDMA schedule.

On the other hand, if the node doesn't receive any REQ_Data from the cluster head when it is awake, it marks itself as suspect of non-member of cluster. During the next frame slot allotted to this node, if the same thing repeats, then it takes the decision that it is not a member of the cluster.

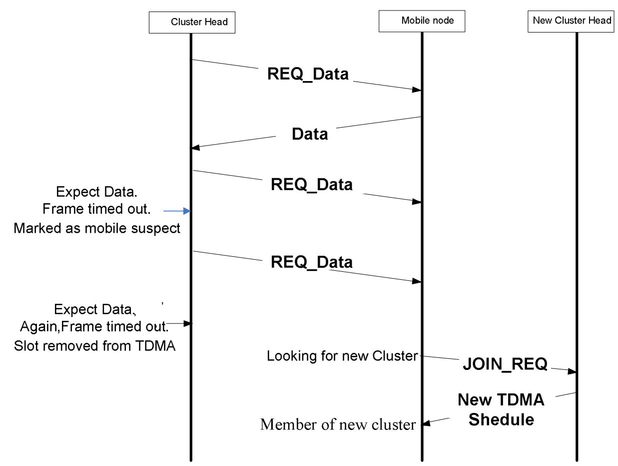

Figure.2 Message sequences for cluster join of a mobile node

Once a node becomes a non-member in any of the cluster, it looks for a cluster to join by sending a broadcast JOIN_REQ. The cluster head hearing the JOIN_REQ allots a time slot in its TDMA schedule and broadcasts it to all the member nodes including the new member. Upon receiving the new TDMA schedule the mobile node now becomes part of the cluster and uses the new cluster schedule. The sequences of messages are shown in Figure 2.

IV. Radio Model for LEACH-ME

The first order radio model used in LEACH and LEACH-M is used for LEACH-ME, where radio dissipates $E_{elec} = 50 nanoJoule / bit$ to drive the transmitter and the transmit-amplifier dissipates $\varepsilon_{elec} = 100 picoJoule / bit / m^2$. It is assumed that radio can be turned on or off as and when required, to save energy. Also the radio spends the minimum energy required to reach the destination. The transmission cost of LEACH-M is different from LEACH-ME because of the additional effort to calculate the remoteness at the ACTIVE slot.

Assuming k-bit message is sent on normal and k_{active} is sent on ACTIVE slot, transmission and receiving cost for a distance of d for k-bit can be calculated as follows

Transmitting cost for LEACH-M:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d) \quad (2)$$

$$= E_{elec} * k + \varepsilon_{elec} * k * d^2 \quad (3)$$

For N nodes in the cluster, the total transmission cost per TDMA cycle is:

$$E_{Tx-cluster}(k,d) = (N-1) * E_{elec} * k + \varepsilon_{elec} * k * \sum_{i=1}^{N} d_i^2 \quad (4)$$

Transmitting cost of LEACH-ME per TDMA cycle is transmitting cost of LEACH-M per TDMA cycle added with active slot cost.

$$E_{Tx-cluster}(k,d) = (N-1) * E_{elec} * k + \varepsilon_{elec} * k * \sum_{i=1}^{N} d_i^2$$

$$+ 2(N-1) * E_{elec} * k_{active} + 2 * \varepsilon_{elec} * k_{active} * \sum_{i=1}^{N} d_i^2 \quad (5)$$

In active slots the k-active bits need to be sent twice, one for ID transmission and other for remoteness transmission. The extra energy dissipated is in the ACTIVE slots to achieve awareness of the remoteness to elect cluster head. The number of bits in active frame is assumed to be less than that of the data frame bits.

Reception cost will be same in LEACH-M and LEACH-ME

Reception cost:

$$E_{Rx}(k) = E_{Rx-elec}(k) \quad (6)$$

$$E_{Rx}(k) = E_{elec} * k \quad (7)$$

The radio channel is assumed to be symmetric for given signal to noise ratio.

V. Experimental Results

To evaluate the performance of LEACH-ME, we simulated LEACH-M and LEACH-ME using 100 random nodes with topology for a 100m x 100m network region. The base Station is located at (50, 50) in the center of the 100m x 100m field. We simulated the wireless sensor network to get the number of data packets that are successful in reaching the base station. The simulation is run by changing the mobility factor for LEACH-M and LEACH-ME. We also simulated the amount of energy dissipations for the data packets transmitted.

Figure 3 shows the average successful communication rate for various mobility factors. At low mobility, the performance of LEACH-M and LEACH-ME are comparable. But as the mobility increases, there is a definite improvement in average successful communication rate in LEACH-ME. As is obvious from figure 4, at the mobility factor of 4.0 the successful communication rate is 16%, which is better than the LEACH-M. On the other hand the amount of energy dissipation as well as computational overhead increases as mobility increases. This is obvious from figure 5 and figure 6. At very high mobility (mobility factor 4 and above), the overhead of LEACH-ME is 22% more than that of the overhead of LEACH-M

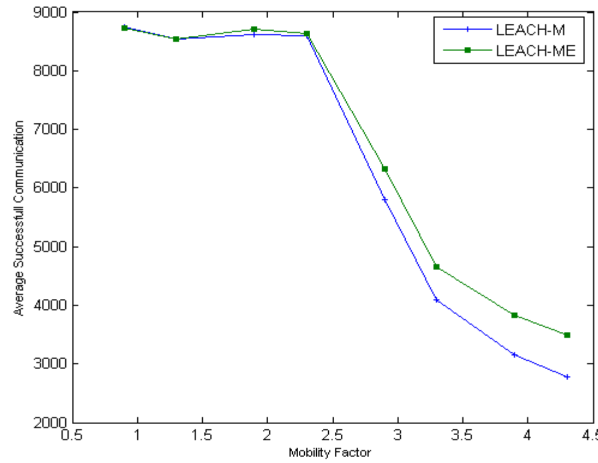

Figure 3 Average successful Communications of Leach-M and LEACH-ME for various mobility factors

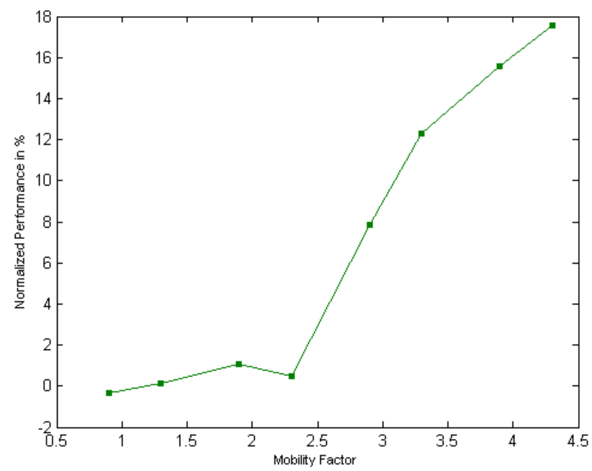

Figure 4 Performance of LEACH-ME over LEACH-M protocol.

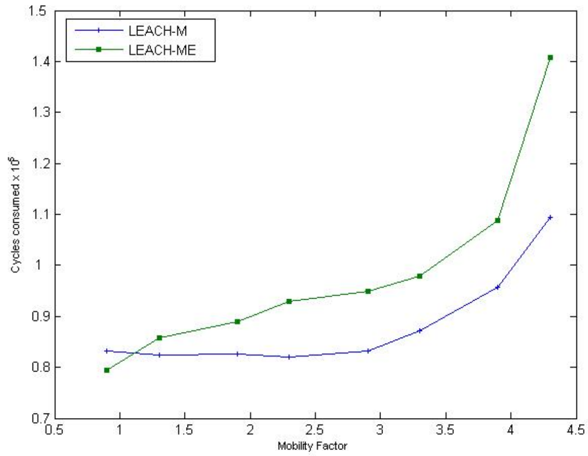

Figure 5 Computational overhead by the LEACH-M and LEACH-ME protocol against the mobility factor

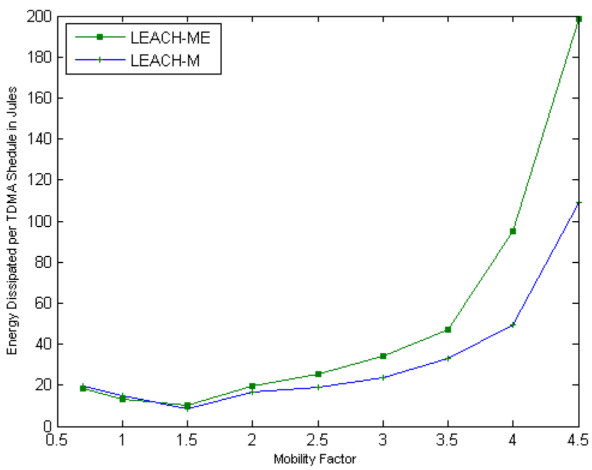

Figure 6 Energy overhead of LEACH-M and LEACH-ME protocols against the mobility factor.

VI. CONCLUSION

In this paper, we describe how the LEACH protocol can be enhanced to handle mobility modulation. The paper makes use of the proposals in LEACH-M protocol where nodes isolated due to mobility from the cluster are reconnected to a new cluster through appropriate mechanism. The proposed LEACH-ME protocol follows the same reconnection mechanism for the isolated node. It uses the concept of remoteness for electing the cluster head.

The simulation experiment shows that the proposed enhanced protocol outperforms LEACH-M in average successful communication rate by a reasonable margin, at very high mobility. It is also clear that to achieve the level of extra performance, energy dissipation needs to be sacrificed at a tolerable level.

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