Routing Protocol Enhancement for handling Node Mobility in Wireless Sensor Networks

G. Santhosh Kumar[1], Vinu Paul M V[2], G. Athithan[3] and K Poulose Jacob[4]

[1,4] Department of Computer Science, Cochin University of Science and Technology, Cochin -682 022, Kerala, INDIA. Email: {san, kpj}@cusat.ac.in

[2,3] Centre for AI and Robotics, DRDO, Bangalore-560 093, INDIA
Email: {vinumanayil, athithan.g}@gmail.com

Abstract— **In wireless sensor networks, the routing algorithms currently available assume that the sensor nodes are stationary. Therefore when mobility modulation is applied to the wireless sensor networks, most of the current routing algorithms suffer from performance degradation. The path breaks in mobile wireless networks are due to the movement of mobile nodes, node failure, channel fading and shadowing. It is desirable to deal with dynamic topology changes with optimal effort in terms of resource and channel utilization. As the nodes in wireless sensor medium make use of wireless broadcast to communicate, it is possible to make use of neighboring node information to recover from path failure. Cooperation among the neighboring nodes plays an important role in the context of routing among the mobile nodes. This paper proposes an enhancement to an existing protocol for accommodating node mobility through neighboring node information while keeping the utilization of resources to a minimum.**

I. Introduction

Wireless sensor networking [1] [2] that combines data sensing, computing, and communication functions has been gaining tremendous popularity in recent days. Most of the work assumes that the sensor network is stationary. However there are certain scenarios, where sensor nodes must be mobile. For instance, in wild life applications, sensors are cast in the field as well as mounted on animals to be monitored. If the node movements are not ordered group motion, mobile nodes in the sensor network lead to frequent path breakage. It is essential to restore a broken path from a node to the sink at the earliest without much cost in terms of energy and channel utilization. The delay in restoring the path may cause both packet loss and large delay in delivery.

One way to solve the problem is to directly adopt ad-hoc routing protocols from MANET domain. But as these protocols are not known to be energy saving, they do not suit sensor nodes with limited supply of energy for mobile wireless sensor network (WSN). Moreover ad-hoc protocols need to maintain route from many to many nodes in contrast to many to one scenario in wireless sensor network. In WSN, nodes only need to maintain route from either to the cluster head or to the nearest sink. Use of ad-hoc routing protocols require extra route information to be maintained at each node without any use.

Up on failure of a route path, different methods have been used to recover from path failure. One method is to reconstruct routing paths periodically. For example, in a simple beacon protocol [3], a base station periodically broadcasts a beacon message. By receiving a beacon message, a node receives an up-to-date routing path to the base station. Reconstruction of routing paths is expensive in this method and consumes a lot of energy. In addition, since re-construction is not on-demand, nodes have to wait until the arrival of beacon to update the routing information on a node failure. In another method, multiple routing paths are used to transfer data. The key idea is that unless every path from a sensor node to a base station is broken by movements of nodes, data can be transmitted to base station. The multi path version of directed diffusion [4] uses this strategy. This method can result in increased energy consumption and packet collisions, because data is sent along multiple paths, irrespective of whether there is a node failure or not.

Providing robustness to routing is an essential requirement to any routing protocol. As the node mobility causes route path breakage at any instant of routing a packet, robustness is essential to reestablish the route at the earliest without much delay. In view of the need for energy saving, sensor networks are mainly organized either in clustered hierarchical manner or as sector-based. In both cases much work has been reported to accommodate mobility.

In self organized clustered hierarchical category, the LEACH protocol [5] is an elegant solution to the energy constraint problem. It forms enough number of clusters in a self organized manner at the start. It then rotates the cluster heads and achieves energy efficiency by a factor of 8. Although LEACH protocol has such advantages, it basically assumes that the nodes are fixed. As LEACH protocol does not consider the mobility of sensor nodes after the “Set-up

Phase" of clusters within a round, it performs poorly with serious data loss in the environment of node mobility.

The enhancement to LEACH to support mobility is addressed in LEACH-Mobile, in short "LEACH-M" [6]. The basic idea in LEACH-M is to confirm whether a mobile sensor node is able to communicate with a specific cluster head or not. This is implemented by transmitting a message, which requests for data transmission back to mobile sensor node from cluster head within a time slot allocated in TDMA schedule of a wireless sensor cluster. If the mobile sensor node does not receive the data transmission from cluster head within an allocated time slot according to TDMA schedule, it sends a join-request message at next TDMA time slot allocated. Then it decides the cluster to which it will belong for this moment by receiving cluster join-ack messages back from specific cluster heads. The LEACH-M protocol achieves definite improvement in data transfer success rates as mobile nodes increase compared to the non-mobility centric LEACH protocol.

LEACH-M handles node mobility well, if the cluster heads are more or less stationary. But it is not true in all the cases, as the cluster head election happens from the same set of mobile nodes. Also the cluster head rotation is purely random and depends on the number of times the node was a cluster head in earlier rounds of TDMA, which is exactly the same way as in basic LEACH protocol. But as the cluster head keeps moving before the rotation happens, cluster itself gets disturbed and an enormous amount of packet loss may occur until the formation of the next new cluster under a new head.

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 [7]). With the modified cluster heads election process, the proposed protocol makes sure that the clusters are disturbed minimally in the event of movement of cluster heads.

II. LEACH-MOBILE-ENHANCED PROTOCOL

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 [8]:

- *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 that 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 proposed in [9]. 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 [7], even though the nodes are in motion, the average link change is minimal, maintaining high spatial dependency. The node movement in such scenarios doesn't 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 $d_{ij}(t)$.

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 * $|t_2-t_1|$.

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

Figure.1 TDMA time slots in LEACH-ME protocol

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.

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. 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 nodes move. A probable figure could be of the order of 5 -15 % of the total number of nodes.

D. 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 frame 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 frame 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.

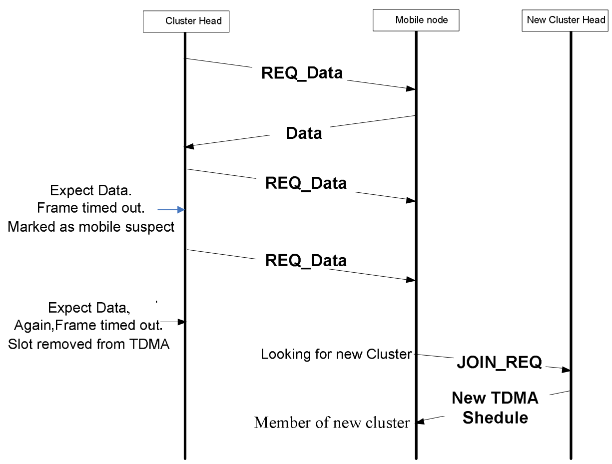

Figure.2 Message sequences for cluster join of a mobile node

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 node members 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 sequence of messages are shown in Figure 2

III. RADIO MODEL FOR LEACH-ME

The first order radio model [5] 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:

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

$$= E_{elec} * k + \varepsilon_{elec} * k * d^2 \tag{3}$$

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

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

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

$$E_{Tx-cluster}(k,d) = (N-1) * E_{elec} * k + \varepsilon_{elec} * k * \sum_{i=1}^{N} d_i^{\,2}$$
$$+ 2(N-1) * E_{elec} * k_{active} + 2 * \varepsilon_{elec} * k_{active} * \sum_{i=1}^{N} d_i^{\,2} \tag{5}$$

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:

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

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

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

IV. 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

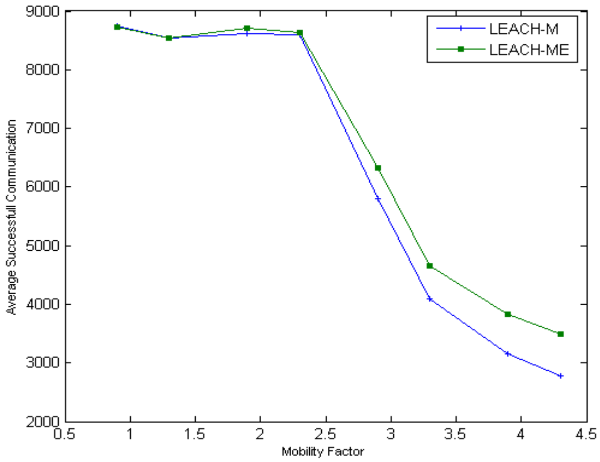

Figure 3 Average successful Communications of Leach-M and LEACH-ME for various mobility factors

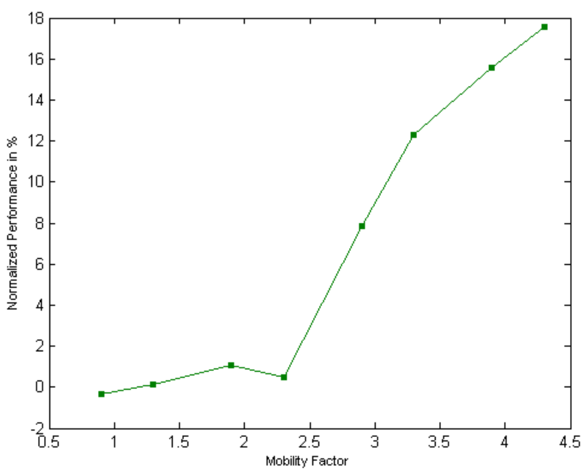

Figure 4 Performance of LEACH-ME over LEACH-M protocol.

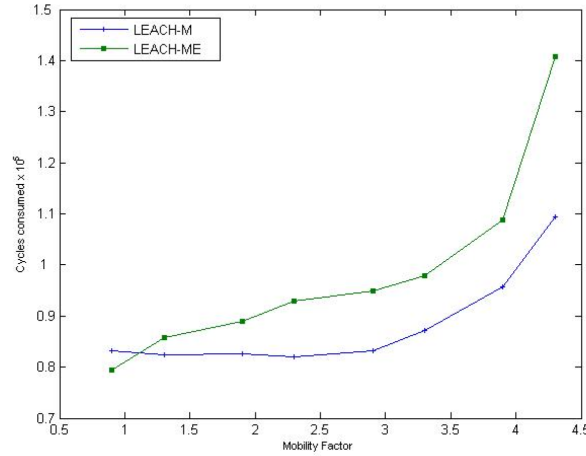

Figure 5 Computational overhead by the LEACH-M and LEACH-ME protocol against the mobility factor

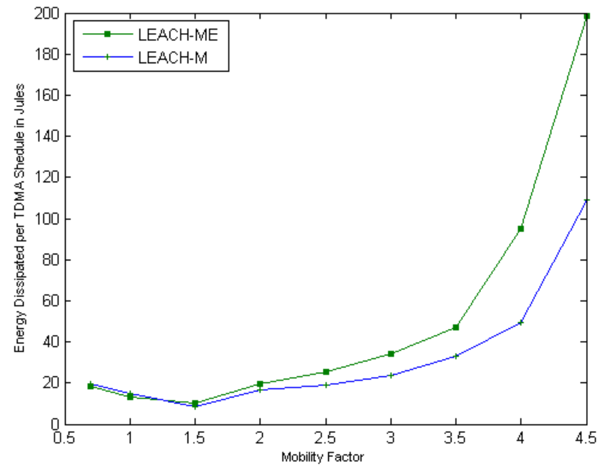

Figure 6 Energy overhead of LEACH-M and LEACH-ME protocols against the mobility factor

V. 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.

ACKNOWLEDGMENT

The authors would like to thank Mr. A.V. Sahadevan for his contribution to the original proposal that led to this paper and for his initial comments on the manuscript.

REFERENCES

[1] F Akylidiz, W. Su, Y Sankarasubramanyam, and E. Cayirci, "Wireless Sensor Network: a survey", *Computer Networks*, Vol. 38 N0. 4, 2002, pp. 393-422

[2] Carlos de Morrais Codeiro, Dhrarma Prakash Agarwal "AD-HOC AND SENSOR NETWORKS, Theory and Applications" Ist Edition, World Scientific Publishing Co. Pte. Ltd., Singapore 2006

[3] D. Ganesan, B. Krishnamurthy, A.Woo, D. Culler, D. Estrin, and S. Wicker. "An empirical study of epidemic algorithms in large scale multihop wireless networks", Technical Report IntelIRP-TR-02-003, Intel Research, March 2002.

[4] D. Ganesan, R. Govindan, S. Shenker, and D. Estrin. "Highly resilient, energy efficient multi path routing in wireless sensor networks", MC2R, 1(2), 2002.

[5] W. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient routing protocols for wireless microsensor networks," in *Proc. 33rd Hawaii Int. Conf. System Sciences (HICSS)*, Maui, HI, 2000.

[6] Do-Seong Kim, Yeong-Jee Chung, "Self-Organization Routing Protocol Supporting Mobile Nodes for Wireless Sensor Network", Proceedings of the First International Multi-Symposiums on Computer and Computational Sciences (IMSCCS'06), 2006

[7] Xiaoyan Hong, Mario Gerla, Guangyu Pei and Ching- Chuan Chiang. "A Group Mobility Model for Ad Hoc Wireless Networks", *ACM International Workshop on* Modeling and Simulation of Wireless and Mobile Systems (MSWiM), August 1999.

[8] Liliana M. Arboleda C.and Nidal Nasser, "Cluster-based Routing Protocol for Mobile Sensor Networks," *QShine'06*, The Third International Conference on Quality of Service in Heterogeneous Wired/Wireless Networks, August 7–9, 2006, Waterloo, Ontario, Canada © 2006 ACM 1-59593-472-3/06/08

[9] B. J. Kwak, N. O. Song, and L. E. Miller, "A Canonical Measure of Mobility for Mobile Ad Hoc Networks",Proceedings IEEE MILCOM 2003, Boston, 13-16 October 2003