An Energy Efficient Routing Scheme for Mobile Wireless Sensor Networks

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***Abstract*— Research on wireless sensor networks has recently received much attention as they offer an advantage of monitoring various kinds of environment by sensing physical phenomenon. Among various issues, energy consumption is one of the most important criteria for routing protocol in wireless sensor networks (WSNs). This paper introduces an energy efficient clustering algorithm for mobile sensor network based on the LEACH protocol. The proposed protocol adds feature to LEACH to support for mobile nodes and also reduces the consumption of the network resource in each round. The proposed protocol is simulated and the results show a significant reduction in network energy consumption compared to LEACH.**

I. INTRODUCTION

Recent technological advantages allow the manufacturing of small and low cost sensing devices to be technically and economically possible. The sensing devices are used to monitor various kinds of ambient conditions like temperature, humidity, etc and then transform them into electric signal. A wireless sensor network contains hundreds or thousands of these sensor devices that have the ability to communicate either directly to the Base Station (BS) or among each other. Usually, sensor nodes are scattered in the sensing field, being the area where we want to monitor some ambient conditions. Sensor nodes have to coordinate among themselves to get information about the physical environment. The information collected by sensor nodes is routed to the Base Station either directly or through other sensor nodes. The Base Station is a fixed node or mobile node, which is capable to connect the sensor network to an infrastructure networks or to the Internet where users can access and process data.

Routing in WSNs is very challenging due to the specific characteristics that distinguish WSNs from other wireless networks such as wireless ad hoc networks or cellular networks. Many new algorithms have been proposed, taking into consideration the inherent features of WSNs along with the application and architecture requirements. Based on the network structure adopted, routing protocols for WSNs can be classified into flat network routing, hierarchical network routing, location-based network routing [2]. In flat network routing, all nodes have the same functionality and they work together to perform sensing and routing tasks. The Sensor Protocols for Information via Negotiation (SPIN) [3] and Directed Diffusion [4] fall into this category. Hierarchical network routing divides the network into clusters to achieve energy-efficient, scalability and one of the famous hierarchical network routing protocol is low-energy adaptive clustering hierarchy (LEACH) [5]. In location-based network routing, location information of nodes is used to compute the routing path. This information can be obtained from global positioning system (GPS) devices attached to each sensor node. Examples of location-based network routing protocols include geography adaptive routing (GAF) [6] and Geographic and Energy-Aware Routing (GEAR) [7].

During the creation of network topology, the process of setting up routes in WSNs is usually influenced by energy considerations. Because the power attenuation of a wireless link is proportional to square or even higher order of the distance between the sender and the receiver, multi-hop routing is assumed to use less energy than direct communication. However, multi-hop routing introduces significant overhead to maintain the network topology and medium access control. In the case that all the sensor nodes are close enough to the BS, direct communication could be the best choice for routing since it reduces network overhead and have a very simple nature. But in most cases, sensor nodes are randomly scattered so multi-hop routing is unquestionably de-facto. Many research projects and papers have shown that the hierarchical network routing and specially the clustering mechanisms make significant improvement in WSNs in reducing energy consumption and overhead [8-9]. We also have to note that most of clustering protocols proposed for WSNs assume that nodes are stationary. The reason for sensor nodes to be taken as stationary is the assumption of simple network topology. Clustering protocols can reduces signalling overhead since they do not have to manage the mobility pattern or location information of sensor nodes. As a result, it allows nodes saving more energy leading to a longer network life time. However, with some applications such as animal tracking, search and rescue activities this assumption is not very realistic; hence there are raising demands for clustering protocols to support mobile nodes.

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The rest of this paper is organized as follows: Section 2 discusses the concepts of clustering protocols mainly focus on LEACH. Section 3 presents the proposed protocol with discussions. The evaluation methodology with simulation results is included in Section 4. Finally, the conclusion is drawn in Section 5 with the indication of future research.

II. Related Work

Clustering is the method by which sensor nodes in a network organize themselves into hierarchical structures. By doing this, sensor nodes can use the scarce network resources such as radio resource, battery power more efficiently. Within a particular cluster, data aggregation and fusion are performed at cluster-head to reduce the amount of data transmitting to the base station. Cluster formation is usually based on remaining energy of sensor nodes and sensor's proximity to cluster-head [10]. Non cluster-head nodes choose their cluster-head right after deployment and transmit data to the cluster-head. The role of cluster-head is to forward these data and its own data to the base station after performing data aggregation and fusion. LEACH is one of the first hierarchical routing protocols for WSNs. The idea proposed in LEACH has inspired many other hierarchical routing protocols [11-13].

A. LEACH and LEACH-C

LEACH (Low-Energy Adaptive Clustering Hierarchy), an energy-conserving routing protocol for wireless sensor network, was proposed by Heinzelman, Chandrakasan and Balakrishnan [5]. The idea is to form cluster of sensor nodes based on signal strength and use the cluster-head as a router to forward data of other nodes in cluster to the base station. The data processing is performed at cluster-heads. LEACH is a dynamic clustering mechanism. Time is divided in rounds/intervals with equal length. At the beginning of the round, cluster-heads is generated randomly among the nodes which have remaining energy higher than the average remaining energy of all the nodes. Each sensor node i generates a random number such that $0 < random < 1$ and compares it to a pre-defined threshold $T(i)$. If $random < T(i)$, the sensor node becomes cluster-head in that round, otherwise it is cluster member.

$$T(i) = \begin{cases} \dfrac{p}{1 - p(r \bmod (1/p))} & if\ i \in C \\ 0 & otherwise \end{cases} \quad (1)$$

where: p is desired percentage of cluster-heads, r the current round and C the set of nodes that have not been cluster-head in the last $1/p$ round. After becoming cluster-heads, the nodes broadcast messages to all nodes to inform the status of them. Non cluster-head nodes decide which cluster-head to join based on the receiving signal strength of these messages. The cluster-heads create schedules and send to all the nodes in the clusters. For the rest of the round, the nodes send data to their respective cluster head nodes, then the cluster-heads aggregate and send the data to the base station. After each round, clusters-heads are re-generated to form new clusters. The cluster-head rotation allows network to spend energy equally between sensor nodes and hence it can lengthen the sensor network life time.

LEACH-centralized (LEACH-C) [5] is similar to LEACH in operation except cluster formation. In LEACH-C, the cluster head selection is carried out at BS. During the setup phase, BS receives from other nodes information about their current locations and remaining energy levels. BS uses the remaining energy level to determine the candidate set for cluster head node. The average node energy is computed and the node has remaining energy falling below this value will be removed from the candidate set. Using the candidate set, BS finds clusters using the simulated annealing algorithm [14] to solve the NP-hard problem of finding k optimal clusters [15]. This algorithm attempts to minimize the total energy that non-cluster head nodes use to transmit their data to cluster head nodes by minimizing the total sum of squared distance between nodes and their cluster head nodes.

Once the cluster head nodes are determined, BS broadcast to all nodes the information including cluster head nodes, clusters member node and transmission schedule for each cluster. Nodes use this information to determine its TDMA slot for data transmission.

B. Disadvantages of LEACH

Despite the obvious advantages in using LEACH protocol for cluster organization, few features are still not supported. LEACH assumes a homogeneous distribution of sensor nodes in the given area. This scenario is not very realistic. Let us consider a scenario in which most of the sensor nodes are grouped together around one or two cluster-heads. As being shown in Fig. 2, cluster-heads A and B have more nodes close to them than the other cluster-heads. LEACH's cluster formation algorithm will end up by assigning more cluster member nodes to both A and B. This could make cluster head nodes A and B quickly running out of energy.

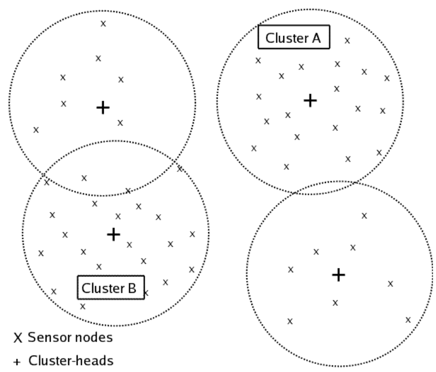

Fig. 1. A Sensor Network

In addition, LEACH does not really support movement of nodes. If a node moves away from its cluster-head, it will have to spend more power in communicating with the current cluster-head. It is really worse if a cluster-head move away from its cluster member nodes. The nodes cannot change its cluster head even if it has another cluster head node closer to itself.

In this paper, we describe additional features to LEACH to solve the issues mentioned above. In the next section, we will present about the algorithm and operations of the proposed protocol called M-LEACH.

III. M-LEACH

The proposed algorithm put some features that LEACH does not support such as:

- Mobility of cluster head and member node during one round
- Currently remaining battery power and the number of nodes per cluster are also considered

In our proposed protocol, we make some assumptions to facilitate the design of clustering mechanism. Here are the assumptions used:

Assumption 1: All the sensor nodes are homogenous in physical characteristics such as initial energy, antenna gain *etc.*

Assumption 2: All the sensor nodes are location-aware. To get the information, sensor nodes can use GPS or other location detect scheme.

Assumption 3: The base station is stationary. At the moment, we only consider the mobility of cluster-heads and cluster-member nodes.

A. Cluster-head location

As mentioned above, our primary objective is to establish a simple mechanism based on LEACH supporting node mobility while still keeping the advantages of LEACH in energy saving.

The principle for en energy based approach is that the receive power is a function of transmit power and attenuation parameter [16].

$$P_{receive} \propto P_{transmit} / r^{\alpha} \tag{2}$$

where: r is transmission distance and α is the RF attenuation exponent. The value of α falls between 2 and 5 depend on transmission distance and transmission environment (outdoor/indoor). To facilitate the computation, in this paper we choose value of $\alpha = 2$ which correspond to the free space communication.

Based on the above attenuation model, the cluster-heads locations are chosen to minimize the total power attenuation. Basically, our clustering mechanism is similar to LEACH; however, we try to optimize the location of cluster-heads a little different. In LEACH, cluster-head set is formed almost randomly. This may lead to an unequal distribution of cluster-head or some cluster-heads being overloaded because of many sensor nodes attached to them. This cluster-head formation algorithm is clearly not good particularly in the case we have mobile nodes. The movements of mobile nodes are unpredictable; hence some of them probably move to the areas that are not covered by any cluster-head. Our idea is to divide the sensing area into sub-areas and try to optimize location of cluster-head in these sub-areas. Let n be the number of sensor nodes in a give sub-area where node i has x-y co-ordinate and distance to cluster-head respectively be x_i, y_i and d_i. From the equation (1) we have the attenuation of transmission between node i and cluster-head is proportional to d_i^2. In order to minimize the total attenuation in the sub-area j, we have to minimize the value of S_j.

$$S_j = \sum_{i=1}^{N_j} d_i^2 \tag{3}$$

By taking derivative of Sj, we can find the optimal location for cluster-head in the sub-area

$$x_j^c = \frac{1}{N_j} \sum_{i=1}^{N_j} x_i \qquad y_j^c = \frac{1}{N_j} \sum_{i=1}^{N_j} y_i \tag{4}$$

We also prefer the nodes that have less mobility to be cluster head nodes. C_i^j is defined as the cost for node i to be cluster head node of cluster k.

$$C_i^j = v_i^* * \sqrt{(x_i - x_j^c)^2 + (y_i - y_j^c)}^2 \qquad v_i^* = \begin{cases} v_t & \text{if } v_i < v_t \\ v_i & \text{otherwise} \end{cases} \tag{5}$$

where: v_i is velocity of node i, x_j^c and y_j^c are given by equation (4), v_t is a threshold of velocity.

The node with smallest C_i^j is chosen to be cluster-head of cluster j. The computation is performed by the base station and then the information is broadcasted to all nodes.

B. Mobility support

In LEACH, mobility is not supported directly. In a round time, if a node moves away from the current cluster-head it has to spend more energy to keep in touch with the current cluster-head. If this node gets closer to another cluster-head, keeping in touch with the current cluster-head could lead to an in-effectiveness in energy utilization. To make sure that mobility of nodes does not affect performance adversely, we need to identify which cluster membership is not good in saving energy and use a hand-off mechanism permitting those nodes to change their cluster-head.

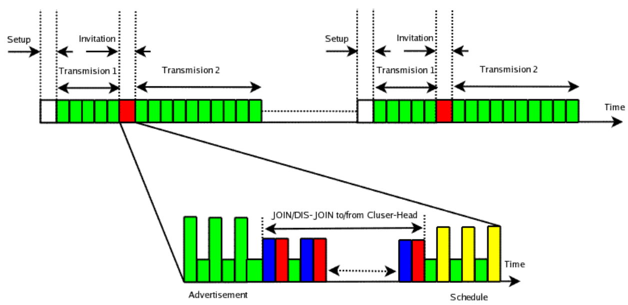

Fig. 2. M-LEACH

For supporting mobility, we used a scheme that comprised of both LEACH-C and LEACH as shown in Fig. 2

During the Setup phase of M-LEACH, each node sends its information including locations, velocity and energy level to BS. Based on the received information, BS will compute the cluster-head set by using equations (4), (5) and send the schedule to all nodes. Each node sets up its cluster-head and schedule to transmit on its own time slot using DSSS spreading code to ensure the minimal inter-cluster interference.

In the transmission phase, each node sends its data during its allocated transmission time slot. Since the duration of time slot is constant, a node can schedule its next allocated time slot base on the number of nodes in this cluster. After receiving data from sensor nodes, cluster head aggregates the data and sends the processed data back to BS.

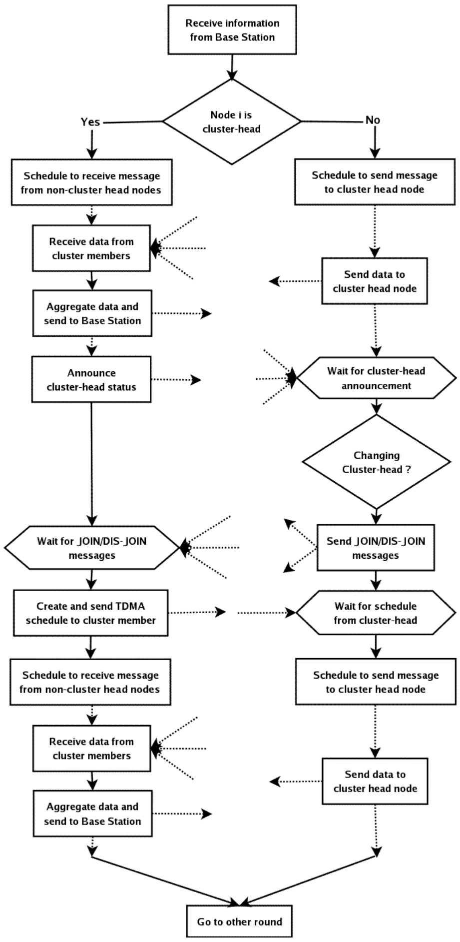

Fig. 3. Flowchart for operation of M-LEACH

During the Invitation phase, the cluster heads must let other nodes know that they have been chosen to be cluster head in this round. To do this, cluster head nodes broadcast Advertisement messages using Carrier-Sense-Multiple Access (CSMA) MAC protocol. In these messages, cluster head nodes also include their willingness (W) which indicates the availability of the cluster for new node to join.

$$W_i^j = \frac{E_i}{N_j} \tag{6}$$

where: E_i is remaining energy of the cluster head node (node i) and N_j is total number of node in the cluster j.

The cost for node m to join to cluster j with cluster head node j is computed as:

$$C_m^a = W_i^j * d_{m,i} \tag{7}$$

where: W_i^j is the willingness of cluster j, $d_{m,i}$ is the distance between node m and cluster head node i.

Based on the above cost (C_m^a), node will choose the cluster with smallest value of C_m^a to join. After each node has decided to which cluster it belongs and compared with the current cluster, if they are different, the node will send DIS-JOIN message to current cluster head node and JOIN message to the new cluster head node. Cluster head add or remove node from its schedule according to the message it has received is JOIN or DIS-JOIN message. Then cluster schedule is broadcasted by cluster head node to the other nodes in the same cluster and the nodes reschedule its transmission accordingly.

After the Invitation phase is another Transmission phase with the same cluster head set but non-cluster head nodes join to the closest cluster head. A flowchart of operation of M-LEACH is shown in Fig. 3.

IV. Simulation of M-LEACH And Results

For our experiments, we used the network topology and energy consumption model provided with LEACH source code [17]. 100 sensor nodes are randomly distributed in an area of 100 m x 100 m. BS is put at the location with $x = 175$, $y = 50$. The bandwidth of data channel is set to 1 Mbps, the length of data messages is 500 bytes and packet header for each type of packet was 25 bytes. The round time is set to 20 s and cluster-head nodes send Invitation after 10 s from the beginning of round. The threshold of velocity is set to 0.3 m/s. Each node begins with 2 J of energy and it has unlimited amount of data to send to the BS. When a node uses energy down to its energy threshold, it can no longer send data and is considered as a dead node.

TABLE I
The Simulation Environment

Parameter	Value
Size of network	100 m x 100 m
Size of packet	500 bytes
E_{elec} (Radio electronics energy)	50 nJ/bit
E_{amp} (Radio amplifier radio)	100 pJ/bit/m^2
E_{init} (Initial energy)	2 J
Number of nodes	100

During the simulation time, we monitor the amount of data is transferred to the BS and the number of alive sensor nodes. In these simulations, we used Random Waypoint with Reflection [18]. We vary the number of mobile sensor nodes m to compare the performance of M-LEACH and LEACH-C. Maximum velocity of mobile sensor nodes is set to 2 m/s.

Figure 4 and 5 represent the simulation results of the simulation we have carried out with Random Waypoint mobility model. Figure 4 shows the total number of nodes alive over time. In figure 5, X-axis denotes the number of data message received at BS and the Y-axis denotes the number of sensor nodes alive. Each data point in the graphical result is computed as the average of 10 different simulations. We can see that M-LEACH can increase both the network live time and number of data items received at the BS. M-LEACH can deliver around 8% more effective data than LEACH-C when dealing with node mobility at various numbers of mobile nodes.

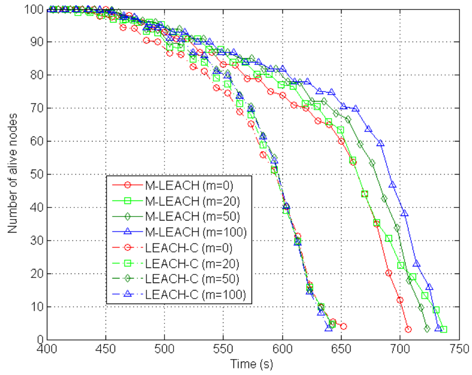

Fig. 4. Number of nodes alive over time with Random Waypoint with Reflection mobility (m is number of mobile nodes)

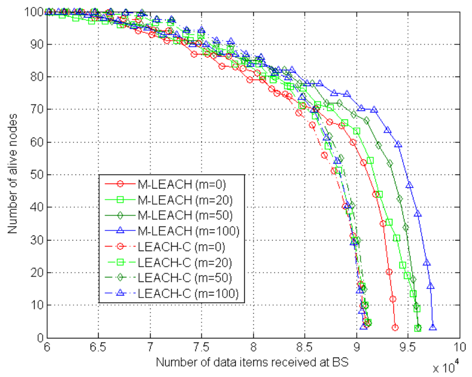

Fig. 5. Number of nodes alive over total data items received at BS with Random Waypoint with Reflection mobility (m is number of mobile nodes)

V. Conclusion

This paper presents an energy efficient sensor network clustering algorithm based on LEACH with mobility-aware. We also implement the proposed algorithm on ns2 simulator and make simulations to compare the performance of M-LEACH and LEACH-C. We show that for a given network topology, our algorithm outperforms LEACH-C in dealing with mobility. Further investigation into mobility model is needed to improve the cluster-head formation. The future work includes developing a theoretical model to compute the optimal value of number of sub-areas, velocity threshold and round time based on a given mobility model. We also believe that our algorithm can offer significant improvement on the performance and energy-efficient of mobile sensor networks if further research on mobility model is carried out.

Acknowledgment

We would like to acknowledge Professor Wendi Heinzelman at University of Rochester for allowing us to reuse the source code of LEACH [19].

The financial support from the 21st century COE program "Verifiable and Evolvable e-Society", Japan Advanced Institute of Science and Technology, is gratefully acknowledged.

References

[1] Al-Karaki, J. N. and A. E. Kamal. Routing techniques in wireless sensor networks: a survey. *IEEE Wireless Communications*, 11(6):6--28, 2004.

[2] Lu, Ye Ming and Vincent W. S. Wong. An energy-efficient multipath routing protocol for wireless sensor networks: research articles. *Int. J. Commun. Syst.*, 20(7):747--766, 2007.

[3] Heinzelman W, Kulik J, Balakrishnan H. Adaptive protocols for information dissemination in wireless sensor networks. *Proceedings of ACM/IEEE MobiCom'99*, Seattle, WA, U.S.A., August 1999; 174–185.

[4] Intanagonwiwat C, Govindan R, Estrin D. Directed diffusion: a scalable and robust communication paradigm for sensor networks. *Proceedings of ACM MobiCom'00*, Boston, MA, U.S.A., August 2000; 56–67.

[5] Heinzelman W, Chandrakasan A, Balakrishnan H. Energy-efficient communication protocol for wireless microsensor networks. *Proceedings of the 33rd International Conference on System Science (HICSS'00)*, Hawaii, U.S.A., January 2000

[6] Xu Y, Heidemann J, Estrin D. Geography-informed energy conservation for ad-hoc routing. *Proceedings of ACM/IEEE MobiCom'01*, Rome, Italy, July 2001; 70–84.

[7] Xu Y, Govindan R, Estrin D. Geographical and energy aware routing: a recursive data dissemination protocol for wireless sensor networks. *Technical Report UCLA/CSD-TR-01-0023*, UCLA Computer Science Department, May 2001.

[8] Hou T. C., Tsai T. J., "An access-based clustering protocol for multihop wireless ad hoc networks", *IEEE Journal on Selected Areas in Communications*, 19(7):1201-1210, July 2001.

[9] Joa-Ng M., Lu I.T., "A Peer-to-peer Zone-based Two-level link state routing for mobile Ad Hoc Networks", *IEEE Journal on Selected Areas in Communications, Special Issue on Ad-hoc Networks*, 17(8):1415-1425, August 1999

[10] C.R. Lin, M. Gerla, Adaptive clustering for mobile wireless networks, *IEEE Journal on Selected Areas in Communications* 15 (7) (1997) 1265–1275.

[11] A. Manjeshwar, D.P. Agrawal, TEEN: a protocol for enhanced efficiency in wireless sensor networks, in: Proceedings of the 1st International Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile Computing, San Francisco, CA, April 2001.

[12] S. Lindsey, C.S. Raghavendra, PEGASIS: power efficient gathering in sensor information systems, in: *Proceedings of the IEEE Aerospace Conference*, Big Sky, Montana, March 2002.

[13] A. Manjeshwar, D.P. Agrawal, APTEEN: a hybrid protocol for efficient routing and comprehensive information retrieval in wireless sensor networks, in: *Proceedings of the 2nd International Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile computing*, Ft. Lauderdale, FL, April 2002.

[14] T. Murata and H. Ishibuchi, "Performance evaluation of genetic algorithms for flowshop scheduling problems," *Proc. 1st IEEE Conf. Evolutionary Computation*, vol. 2, pp. 812–817, June 1994.

[15] P. Agarwal and C. Procopiuc, "Exact and approximation algorithms for clustering," *in Proc. 9th Annual. ACM-SIAM Symp. Discrete Algorithms*, Baltimore, MD, Jan. 1999, pp. 658–667.

[16] Feng Zhao and Leonidas Guibas, "Wireless sensor network – an information processing approach", *Morgan Kaufmann Publishers*, pp. 7-8.

[17] http://www.ece.rochester.edu/~wheinzel/research.html

[18] T. Camp, J. Boleng, and V. Davies, "A survey of mobility models for ad hoc network research," *Wireless Communications & Mobile Computing (WCMC): Special issue on Mobile Ad Hoc Networking: Research, Trends and Applications*, vol. 2, no. 5, pp. 483-502, 2002

[19] http://www.ece.rochester.edu/research/wcng/code/index.htm