MiSense Hierarchical Cluster-Based Routing Algorithm (MiCRA) for Wireless Sensor Networks

Kavi K. Khedo, and R. K. Subramanian

Abstract—Wireless sensor networks (WSN) are currently receiving significant attention due to their unlimited potential. These networks are used for various applications, such as habitat monitoring, automation, agriculture, and security. The efficient node-energy utilization is one of important performance factors in wireless sensor networks because sensor nodes operate with limited battery power. In this paper, we proposed the MiSense hierarchical cluster based routing algorithm (MiCRA) to extend the lifetime of sensor networks and to maintain a balanced energy consumption of nodes. MiCRA is an extension of the HEED algorithm with two levels of cluster heads. The performance of the proposed protocol has been examined and evaluated through a simulation study. The simulation results clearly show that MiCRA has a better performance in terms of lifetime than HEED. Indeed, MiCRA our proposed protocol can effectively extend the network lifetime without other critical overheads and performance degradation. It has been noted that there is about 35% of energy saving for MiCRA during the clustering process and 65% energy savings during the routing process compared to the HEED algorithm.

Keywords—Clustering algorithm, energy consumption, hierarchical model, sensor networks.

I. INTRODUCTION

WIRELESS Sensor Networks (WSNs) are formed by a set of nodes that gather information and forward it to a sink. They are formed by small, inexpensive and resource limited devices that can interact with the environment (sensing or actuating) and communicate in a wireless manner with other devices [1]. Sensor networks are emerging as a new tool for habitat monitoring in nature preserves, monitoring and gathering events in hazardous environments, surveillance of buildings, and surveillance of enemy activities in a battlefield environment.

WSNs present a new challenge research problem due to their high flexibility to support several real-world applications making the definition of a global technical solution for all of them difficult [2]. The core operation of wireless sensor network is to collect and process data at the network nodes, and transmit the necessary data to the base station for further analysis and processing. Due to large network size, limited

K. K. Khedo is with the Computer Science Department, University of Mauritius, Reduit, Mauritius (e-mail: k.khedo@uom.ac.mu).

R. K. Subramanian is with the Computer Science Department, University of Mauritius, Reduit, Mauritius (e-mail: rks@uom.ac.mu).

power supply, and inaccessible remote deployment environment, the WSN-based protocols are different from the traditional wireless protocols [3]. Currently there are several energy efficient communication models and protocols that are designed for specific applications, queries, and topologies.

Nodes in a sensor network are severely constrained by energy, storage capacity and computing power. To prolong the lifetime of the sensor nodes and the whole network, designing efficient routing protocols is critical. A number of routing protocols have been developed to make these networks practical and efficient [4]. These protocols attempt to make the constituents nodes work in unison to achieve a specific task or tasks. Invariably they seek to minimize energy expenditure and maximize network lifetime.

The routing protocol of sensor networks is typically partitioned into two sub routings: (1) flat routing protocol and (2) hierarchical routing protocol. The sensor node performs a data aggregation process to avoid duplicated data transfers. Such a sequence of processes favors the hierarchical routing protocol based upon clusters due to the fact that efficient selection of cluster heads can reduce the usage of consumption power and maximize the life time of the networks [5].

In this paper, we proposed the MiSense hierarchical cluster based routing algorithm (MiCRA). We demonstrate that the algorithm extend the lifetime of sensor networks and maintain a balanced energy consumption of nodes. All nodes in the sensor network execute a first level clustering algorithm which is based on the HEED algorithm and only first level cluster heads participate in the second level election. The second level election uses a new approach to calculate the cluster head probability which helps to cluster the network in two rounds only, while the conventional approach in HEED algorithm terminates in six rounds, hence resulting in a reduction of energy consumption.

II. RELATED WORKS

Hierarchical or cluster-based routing, originally proposed in wireline networks, are well-known techniques with special advantages related to scalability and efficient communication. As such, the concept of hierarchical routing is also utilized to perform energy efficient routing in WSNs. In a hierarchical architecture, higher energy nodes can be used to process and

send the information while low energy nodes can be used to perform the sensing in the proximity of the target. This means that creation of clusters and assigning special tasks to cluster-heads can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the base station. Hierarchical routing is mainly two-layer routing where one layer is used to select cluster-heads and the other layer is used for routing.

Heinzelman et al. [6] introduced a hierarchical clustering algorithm for sensor networks, called Low Energy Adaptive Clustering Hierarchy (LEACH). LEACH is a cluster-based protocol, which includes distributed cluster formation. LEACH randomly selects a few sensor nodes as cluster-heads (CHs) and rotate this role to evenly distribute the energy load among the sensors in the network. In LEACH, the cluster-head (CH) nodes compress data arriving from nodes that belong to the respective cluster, and send an aggregated packet to the base station in order to reduce the amount of information that must be transmitted to the base station. Although LEACH is able to increase the network lifetime, there are still a number of issues about the assumptions used in this protocol. LEACH assumes that all nodes can transmit with enough power to reach the base station if needed and that each node has computational power to support different MAC protocols. Therefore, it is not applicable to networks deployed in large regions. It also assumes that nodes always have data to send, and nodes located close to each other have correlated data. It is not obvious how the number of the predetermined CHs (p) is going to be uniformly distributed through the network. Therefore, there is the possibility that the elected CHs will be concentrated in one part of the network. Hence, some nodes will not have any CHs in their vicinity.

Lindsey and Raghavendra [7] proposed an enhancement over LEACH protocol. The protocol, called Power-Efficient Gathering in Sensor Information Systems (PEGASIS), is a near optimal chain-based protocol. The basic idea of the protocol is that in order to extend network lifetime, nodes need only communicate with their closest neighbors and they take turns in communicating with the base station. When the round of all nodes communicating with the base station ends, a new round will start and so on. This reduces the power required to transmit data per round as the power draining is spread uniformly over all nodes. Hence, PEGASIS has two main objectives. First, increase the lifetime of each node by using collaborative techniques and as a result the network lifetime will be increased. Second, allow only local coordination between nodes that are close together so that the bandwidth consumed in communication is reduced. Unlike LEACH, PEGASIS avoids cluster formation and uses only one node in a chain to transmit to the base station instead of using multiple nodes.

Simulation results showed that PEGASIS is able to increase the lifetime of the network twice as much the lifetime of the network under the LEACH protocol. Such performance gain is achieved through the elimination of the overhead caused by dynamic cluster formation in LEACH and through decreasing the number of transmissions and reception by using data aggregation. Although the clustering overhead is avoided, PEGASIS still requires dynamic topology adjustment since a sensor node needs to know about energy status of its neighbors in order to know where to route its data. Such topology adjustment can introduce significant overhead especially for highly utilized networks.

Two hierarchical routing protocols called TEEN (Threshold-sensitive Energy Efficient sensor Network protocol), and APTEEN (Adaptive Periodic Threshold-sensitive Energy Efficient sensor Network protocol) are proposed in [8] and [9], respectively. These protocols were proposed for time-critical applications. In TEEN, sensor nodes sense the medium continuously, but the data transmission is done less frequently. A cluster-head sensor sends its members a hard threshold, which is the threshold value of the sensed attribute and a soft threshold, which is a small change in the value of the sensed attribute that triggers the node to switch on its transmitter and transmit. Thus the hard threshold tries to reduce the number of transmissions by allowing the nodes to transmit only when the sensed attribute is in the range of interest. The soft threshold further reduces the number of transmissions that might have otherwise occurred when there is little or no change in the sensed attribute. A smaller value of the soft threshold gives a more accurate picture of the network, at the expense of increased energy consumption. Thus, the user can control the trade-off between energy efficiency and data accuracy. When cluster-heads are to change, new values for the above parameters are broadcast. The main drawback of this scheme is that, if the thresholds are not received, the nodes will never communicate, and the user will not get any data from the network at all.

Simulation of TEEN and APTEEN has shown that these two protocols outperform LEACH. The experiments have demonstrated that APTEENs performance is somewhere between LEACH and TEEN in terms of energy dissipation and network lifetime. TEEN gives the best performance since it decreases the number of transmissions. The main drawbacks of the two approaches are the overhead and complexity associated with forming clusters at multiple levels, the method of implementing threshold-based functions, and how to deal with attribute-based naming of queries.

HEED (Hybrid Energy-Efficient Distributed clustering) [10] is an energy-efficient approach for clustering nodes in sensor networks, it periodically selects cluster heads according to a hybrid of their residual energy and a secondary parameter, such as node proximity to its neighbors or node degree. HEED does not make any assumptions about the distribution or density of nodes, or about node capabilities, e.g., location-awareness. The clustering process terminates in *O(1)* iterations, and does not depend on the network topology or size. The protocol incurs low overhead in terms of processing cycles and messages exchanged. It also achieves fairly

uniform cluster head distribution across the network.

In HEED, clustering is triggered every $T_{CP} + T_{NO}$ seconds to select new cluster heads, where T_{CP} is the time taken for the clustering process and T_{NO} is the time between the end of a T_{CP} interval and the start of the subsequent T_{CP} interval. At each node, the clustering process requires a number of iterations. Every step takes time tc, which should be long enough to receive messages from any neighbor within the cluster range. An initial percentage of clusters heads among all N nodes, Cprob (say 5%) is set, assuming that an optimal percentage cannot be computed a priori. Cprob is only used to limit the initial cluster head announcements, and has no direct impact on the final clusters. Before a node starts executing HEED, it sets its probability of becoming a cluster head, CHprob, as follows:

$$CHprob = Cprob \times \frac{Eresidual}{E\max}$$

where Eresidual is the estimated current residual energy in the node, and Emax is a reference maximum energy (corresponding to a fully charged battery), which is typically identical for all nodes.

The amount of energy spent for the clustering process depends on the number of iterations. The latter depends on the CHprob formula. In Heed the clustering process terminates in six rounds; hence in order to have more savings in terms of energy, the clustering process must terminate in fewer rounds.

III. MiSense Hierarchical Cluster Based Routing Algorithm

Our hierarchical cluster-based routing scheme, MiCRA, is suitable for different types of sensor networks applications such as habitat and environmental monitoring applications. The proposed routing scheme is based on the fact that the energy consumed to send a message to a distant node is far greater than the energy needed for a short range transmission. The main aim of MiCRA is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a particular cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink.

MiCRA uses two important parameters in order to prolong the lifetime of the sensor network. The first parameter is the "residual energy" of nodes which is used to probabilistically select an initial set of cluster heads and the second one is the intra-cluster "communication cost" which is used to break "ties". A tie in this context means that a node falls within the "range" of more than one cluster head, including the situation when two tentative cluster heads fall within the same range.

MiCRA consists of electing 2 levels of cluster-heads (CHs). The first level election uses the same CHprob equation as in the HEED algorithm as described in section three above, whereas the second level election is different from the first one where only the first level CH participate and their CHprob is calculated according to the following equation:

$$CH_{\Pr ob} = \left(\frac{Eresidual}{E\max} \times \left(1 - \frac{ClusterSize}{NumNodes} \right) \right)$$

In the 2nd level CH election, the 2nd level CHs have an unequal topology, where the 2nd level CHs which are near the base station have less members associated with it compared to those that are far away. The advantage derived from such topology is that it prevents second level cluster heads from depleting fast due to heavy relay and intra cluster traffic. In such case, a 1st level CH will join the 2nd level CH with highest residual energy. To achieve such a topology, each node decreases its competition radius as it nears the BS hence resulting in an unequal topology.

The main objective of MiCRA is that it is more efficient for the relaying of packets to the base station. In this new scheme, fewer nodes are involved for transmitting packets to the base station compared to HEED thus reducing the overall consumption of energy in the network and thus helping in prolonging the network lifetime.

The competition radius (Rcomp) is a function of a node distance to the base station is given by:

$$R_{comp} = \left(1 - c \frac{d_{\max} - d(s_i, BS)}{d_{\max} - d_{\min}} \right) R_{comp}^0$$

R_{comp}^0 is the maximum competition radius which is predefined.

dmax and dmin denote the maximum and minimum distance between sensor nodes and the base station.

d(si ,BS) is the distance between a node si and the base station.

c is a constant coefficient between 0 and 1.

MiCRA Algorithm Design

I. Initialise

(a)   Calculate communication range of node using formula (6):

$$R_{comp} = \left(1 - c \frac{d_{\max} - d(s_i, BS)}{d_{\max} - d_{\min}} \right) R_{comp}^0$$

(b)   For each node within communication range
Add node id of each neighbour found in an array (Snbr)
(c)   Calculate cost of each node based on residual energy of node
(d)   For each neighbour found in Snbr array
Send cost
(e)   Calculate cluster head probability based on formula (2)

$$CH_{\Pr ob} = \left(\frac{Eresidual}{E\max} \times \left(1 - \frac{ClusterSize}{NumNodes} \right) \right)$$

(f) Set "Is_Final_CH" attribute to False

II. Repeat

Repeat
(a)   For each node in Snbr
    If node is a Tentative CH or a Final CH
      Add that node to an array (Sch array)
(b)   If Sch is not empty
    Find node with least cost in the Sch array
    My_cluster_head   least_cost(Sch)
    If my_cluster_head = nodeid
      If(Chprob = 1)

          *Inform all
          neighbours(Snbr array)
          that I am a Final Cluster
          Head
          Is_Final_Ch   True*

      Else
        Inform all neighbours that I am a Tentative CH
    Else if(Chprob = 1)
          Inform all neighbours(Snbr array) that I am
          a Final Cluster Head
          Is_Final_Ch   True
    Else if (Random(0,1) <= Chprob
      Inform all neighbours that I am a Tentative CH
(c)   CHprevious   Chprob
(d)   Chprob   minimum(Chprob x 2, 1)
UNTIL Chprevious = 1

III. Finalise

(a)   If(is_final_Ch = False)
    If(Sch contains atleast 1 final Ch)
      My_cluster_head   least_cost(Sch)
      Join_cluster of least_cost node in Sch
(b)   Else advertise myself as a final Ch
(c)   Else advertise myself as a final Ch

IV. SIMULATION STUDY

A simulation study has been carried out to compare MiCRA with the HEED algorithm with respect to the energy spent to perform the clustering and routing process.

The following radio model has been used:

A sensor spends E_{elec} = 50nJ/bit to run the transmitter or receiver circuitry and E_a= 100pJ/bit/m^2 for the transmitter amplifier. To transmit a *k*-size packet over a distance of *d* using the above radio model, the amount of energy consumed for transmission E_{Tx}, is:

$$E_{Tx} = (E_{elec} * k) + (E_a * k * d^2)$$

And the amount of energy E_{Rx} spent to receive a k-bit size message is:

$$E_{Rx} = (E_{elec} * k)$$

The parameters that were varied were the number of nodes in the network (the clustering and routing process of the different algorithms are tested with different number of nodes) and the grid size which represents the area on which the nodes are deployed is varied. The total energy spent by the whole network for the clustering process and the total energy spent by the whole network when each sensor node sends a packet to the base station are monitored. The following parameters

are assumed in the network.

TABLE I
SIMULATION PARAMETERS

Parameters	Value	Motivations for using these values
Initial Energy of nodes	2 J	Standard energy values used for batteries in most sensor nodes.
Broadcast size packet	11 bit	Assume that the sensor is broadcasting an ID of 11 bits.
Routing size packet	11 bit	Assume that the sensor is routing packets of size 11 bits.
E_{elec}	50 nJ/bit	Energy per bit for running circuitry
E_{amp}	100 pJ/bit/m^2	Energy per bit per meter sq for running transmitter amplifier to achieve proper signal to noise ratio

Selected simulation results are given below.

Scenario 1 – Dimension of grid constant, Number of nodes varies, Grid Size 500m x 500m

Output Description: Measure energy dissipated for clustering the network.

TABLE II
ENERGY SPENT IN CLUSTER FORMATION VS. NUMBER OF SENSOR – GRID SIZE 500x500

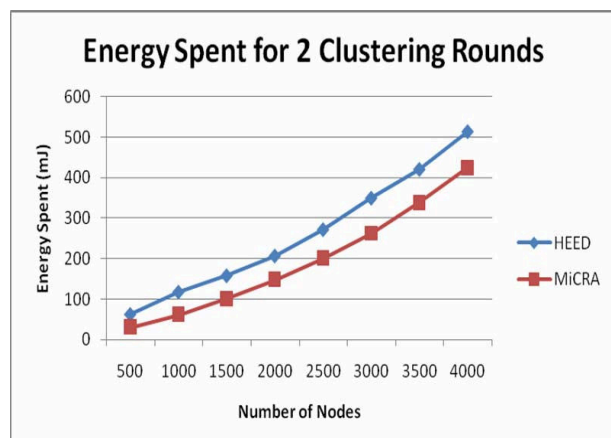| Number of Nodes	HEED	MiCRA
500	62.29	30.31
1000	117.19	62.36
1500	157.36	101.07
2000	206.23	148.07
2500	270.95	201.06
3000	348.49	262.26
3500	419.56	338.63
4000	512.39	425.22

Fig. 1 Number of nodes versus energy spent (Grid Size fix 500m x 500m)

The values in the above table and the graph show the energy consumed in millijoules for clustering a WSN of size 500m x 500m. The graph above shows that, MiCRA consumes less energy compared to the HEED algorithm.

Scenario 2 – Dimension of grid constant. Number of nodes varies, Grid Size: 500m x 500m
Output Description: Measure energy dissipated for routing 1 packet to the base station.

TABLE III
ENERGY SPENT TO ROUTE 1 PACKET VS. NUMBER OF NODES (GRID SIZE: 500 X 500)

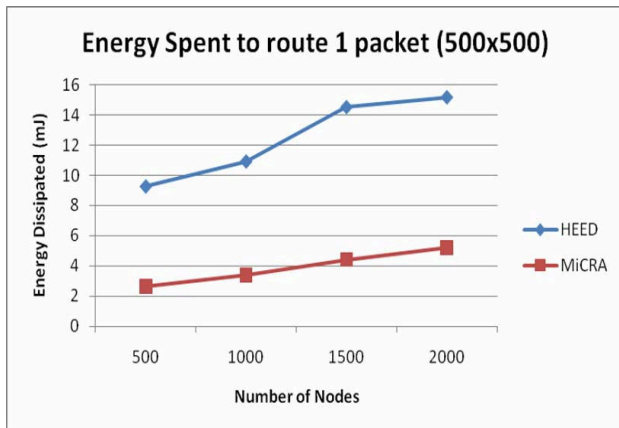| Number of Nodes	HEED	MiCRA
500	9.27	2.63
1000	10.92	3.40
1500	14.51	4.42
2000	15.16	5.23

Fig. 2 Number of nodes versus energy spent (500x500)

The above table and graph show the energy consumed to route 1 packet from a cluster head till the base station is reached. MiCRA still consumes less amount of energy for a grid size of 500m x 500m.

Scenario 3 – Dimension of grid constant. Number of nodes varies, Grid Size: 400m x 400m
Output Description: Measure energy dissipated for routing 1 packet to the base station.

TABLE IV
ENERGY SPENT TO ROUTE 1 PACKET VS. NUMBER OF NODES (GRID SIZE: 400 X 400)

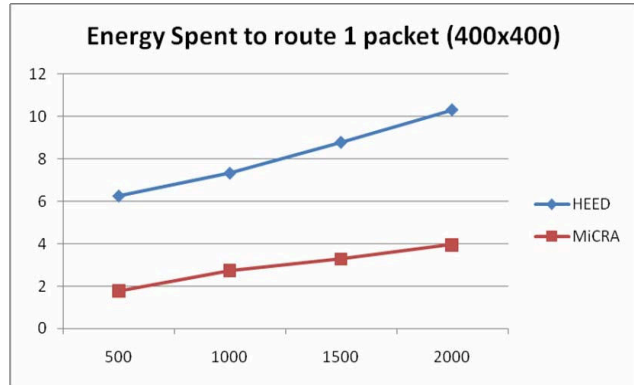| Num of Sensor	HEED	MiCRA
500	6.24	1.78
1000	7.32	2.74
1500	8.78	3.29
2000	10.32	3.96

Fig. 3 Number of nodes versus energy spent (400x400)

The above table and graph show the energy consumed to route 1 packet from a cluster head till the base station is reached. MiCRA consumes less amount of energy for a grid size of 400m x 400m.

V. CONCLUSION

In this paper, we have presented MiCRA, a hierarchical cluster based routing protocol for wireless sensor networks. In MiCRA cluster heads are randomly selected based on their residual energy, and nodes join clusters such that communication cost is minimized. Moreover, the algorithm terminates in a constant number of iterations, independent of the network diameter. Simulation results show that MiCRA prolongs network lifetime, and the clusters it produces exhibit several appealing characteristics. In MiCRA, parameters such as the minimum selection probability and network operation interval, can be easily tuned to optimize resource usage according to the network density and application requirements.

In MiCRA 1st level cluster heads has a high probability of being elected as a cluster if it is rich in residual energy and if it has the lowest number of sensor nodes associated with it. This condition has been possible using the following formula:

$$CH_{Prob} = \left(\frac{Eresidual}{E\max} \times \left(1 - \frac{ClusterSize}{NumNodes} \right) \right)$$

The use of the above parameter has helped to reduce the number of rounds during the clustering process from approximately 6 (in HEED) to 2, hence resulting in a reduction of energy consumption.

Moreover, the 2nd level cluster heads in MiCRA are elected in an unequal way, i.e. 2nd cluster heads that are near the base station have less 1st level cluster head associated with it compared to the 2nd level cluster heads that are far away from the base station. The advantage of this kind of topology is that 2nd level cluster heads that are near the base station normally have a lot of relay traffic to do, hence, reducing their number of 1st level cluster head members will help them carry out their assigned tasks for a longer period. This scheme was implemented using the following formula:

$$R_{comp} = \left(1 - c \frac{d_{max} - d(s_i, BS)}{d_{max} - d_{min}}\right) R_{comp}^0$$

MiCRA obtains around 35% of energy saving compared to HEED for the clustering process and for the routing process of 1 packet by each node, our algorithm show 65% energy saving. These two results clearly show that MiCRA outperforms the HEED algorithm. Moreover, our approach can be applied to the design of several types of sensor network protocols that require energy efficiency, scalability, prolonged network lifetime, and load balancing.

REFERENCES

[1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "Wireless sensor networks: a survey," Computer Networks, vol. 38, no. 4, 393–422, 2002.

[2] H. Karl, A. Willig, et al. "Protocols and Architectures for Wireless Sensor Networks," John Wiley and Sons, 2005.

[3] D. Estrin, D. Culler, K. Pister, and G. Sukhatme, "Connecting the physical world with pervasive networks," IEEE Pervasive Computing, 59–69, January-March 2002.

[4] J. Hill, R. Szewczyk, A. Woo, S. Hollar, D. Culler, and K. Pister, "System architecture directions for networked sensors," In Proceedings of the 9th International Conference on Architectural Support for Programming Languages and Operating Systems, November 2000.

[5] J. Ibriq and I. mahgoub, "Cluster-Based Routing in Wireless Sensor Networks: Issues and Challenges," Proceedings of the 2004 Symposium on Performance Evaluation of Computer Telecommunication Systems, 759-766, July 2004.

[6] W.B Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Microsensor Networks," In the Proceedings of the 33rd Hawaii International Conference on System Sciences (HICSS '00), January 2000.

[7] S. Lindsey and C. Raghavendra, "PEGASIS: Power-Efficient Gathering in Sensor Information Systems," IEEE Aerospace Conference Proceedings, 2002, vol. 3, no. 9-16, 1125-1130.

[8] A.Manjeshwar and D.P. Agarwal, "TEEN: a routing protocol for enhanced efficiency in wireless sensor networks," In the 1st International Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile Computing, April 2001.

[9] A.Manjeshwar and D.P. Agarwal, "APTEEN: A hybrid protocol for efficient routing and comprehensive information retrieval in wireless sensor networks," In the Parallel and Distributed Processing Symposium., Proceedings International, IPDPS 2002, 195-202.

[10] O. Younis and S. Fahmy, "Distributed Clustering in Ad-hoc Sensor Networks: A Hybrid, Energy-Efficient Approach," In Proceedings of IEEE INFOCOM, vol. 1, 629-640, March 2004.