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Energy and Distance Based Clustering: An Energy Efficient Clustering Method for Wireless Sensor Networks

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***Abstract*—**In this paper, we propose an energy efficient cluster based communication protocol for wireless sensor network. Our protocol considers both the residual energy of sensor nodes and the distance of each node from the BS when selecting cluster-head. This protocol can successfully prolong the network's lifetime by 1) reducing the total energy dissipation on the network and 2) evenly distributing energy consumption over all sensor nodes. In this protocol, the nodes with more energy and less distance from the BS are probable to be selected as cluster-head. Simulation results with MATLAB show that proposed protocol could increase the lifetime of network more than 94% for first node die (FND), and more than 6% for the half of the nodes alive (HNA) factor as compared with conventional protocols.

***Keywords*—**Clustering methods, energy efficiency, routing protocol, wireless sensor networks.

I. Introduction

RECENT advances in micro-electro-mechanical-systems (MEMS), smart sensors and low power RF have enabled the construction of relatively cheap and low-power wireless micro sensors [1], [2], [3]. A Wireless Sensor Network (WSN) contains hundreds or thousands of such sensor nodes. These tiny sensor nodes consist of sensing, data processing and communicating components. A wireless sensor network generally consists of a base station (BS) that can communicate with a number of wireless sensors via radio link.

Data are collected at a sensor node and transmitted to the BS directly or by means of other nodes. All collected data for a specific parameter like temperature, pressure, humidity, etc are processed in the BS and then the expected amount of the parameter will be estimated. In these networks, the position of sensor nodes need not be engineered or pre-determined, which allows random deployment in inaccessible terrains or disaster relief operations.

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On the other hand, this also means that sensor network protocols must possess self-organizing capabilities. Sensor networks may consist of many different types of sensors such as seismic, thermal, visual, infrared, strain, etc. These networks can be employed in remote or inhospitable environments such as border monitoring, forest fire detection, battlefield observation and industrial automation processes [4].

There are many tight constraints in the design of micro sensor networks such as small size, light weight, low energy consumption and low cost [15]. Among these, energy efficiency should be considered as one of the most critical issues since it is impractical or impossible to replace batteries on thousands of micro sensors. Furthermore, in some cases the micro sensors may not be accessible for battery replacement. On the other hand, decreasing energy consumption in the WSNs has a direct relationship with the increase of their lifetime, which has special importance. To prolong the lifetime of these networks, we will try to balance the energy consumption among the network nodes so that the distribution of energy load in the network will be evenly. Even distribution of energy load causes network nodes to lose their energy with little differences relative to each other, which means the difference of death time of the first node and that of the last one will be relatively short. Even distribution of energy load and increasing the lifetime of the network will guarantee that the data are gathered from all over of the network resulting in a higher quality of service.

Communication protocols highly affect the performance of WSNs by an evenly distribution of energy load and decreasing their energy consumption and thereupon prolonging their lifetime. Thus, designing energy-efficient protocols is crucial for prolonging the lifetime of WSNs [5]. Among the proposed communication protocols, hierarchical (cluster based) ones have significant saving in the total energy consumption of wireless micro sensor network [18]. In these protocols, the sensor nodes are grouped into a set of disjoint clusters. Each cluster has a designated leader, the so-called cluster-head (CH). Nodes in one cluster do not transmit their gathered data directly to the BS, but only to their respective cluster-head. Accordingly, the cluster-head is responsible for: 1) coordination among the cluster nodes and aggregation of their data, and 2) transmission of the aggregated data to the BS, directly or via multi-hop transmission. Each sensor only belongs to one cluster and communicates with the BS only through the cluster header node in the cluster. 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 to decrease the number of transmitted messages to the BS.

Till now, several cluster-based protocols have been proposed for wireless sensor networks but in none of these protocols (LEACH [6][7],TEEN [8], APTEEN [9], DBS [14], EMPAC [10], FTPASC [11], SOP [12]), residual energy in node and each nod's distance from BS in clustering process have not been considered. For this reason, these protocols couldn't distribute energy load in the network well. In this article, by the use of the present hierarchical protocols and especially LEACH protocol and by considering residual energy and distance parameters in clustering process, an energy-efficient communication protocol with the maintenance of the network's scalability have been presented. In this protocol, like [14], we divide the whole network to concentrate circuit segments around BS; the closer this segment is to BS, the more will be the number of its CHs. On the other hand, between each segment's nodes, those who have more energy have the stronger possibility for becoming CH, hence the name of the protocol "*Energy and Distance Based Clustering*".

The remainder of this paper is organized as follows: A brief introduction of LEACH protocol is presented in Section II. In Section III, we introduce some preliminary notions concerning the proposed protocol. Section IV describes the design of our novel protocol in detail. Simulation and results are discussed in Section V. Finally, conclusions are made in Section VI.

II. Related Works

LEACH (low energy adaptive clustering) [6,7] is the most well known energy-efficient clustering protocol for WSNs that uses coordination in the clustering process. In LEACH the nodes organize themselves into local clusters, with one node acting as a cluster-head and exploiting data aggregation in the routing protocol to reduce the amount of data packet that must be transmitted to the BS. The operation of LEACH is divided into rounds. Each round begins with a set-up phase when the clusters are organized, followed by a steady-state phase when data are transferred from the nodes to the BS, as shown in fig1. During the set-up phase, a sensor node chooses a random number between 0 and 1. if this random number is less than the threshold T(n), the sensor node become a cluster-head for the current round. The threshold is set as follows:

$$T(n) = \begin{cases} \dfrac{p}{1 - p \times (r \bmod \frac{1}{p})} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Where P is the desired percentage to become a cluster-head; r, the current round and G, the set of nodes that have not being selected as a cluster-head in the last 1/p rounds. After the cluster-heads are selected, the cluster-heads advertise to all sensor nodes in the network that they are the new cluster-heads. And then other nodes organize themselves into local clusters by choosing the most appropriate cluster-head (normally the closest cluster-head). During the steady-state phase the cluster-heads receive sensed data from cluster members (according to TDMA schedule that was created and transmitted to them), and transfer the aggregated data to the BS. This algorithm ensures that every node becomes a cluster-head exactly once within 1/P rounds, that we call this number of rounds as epoch in this paper.

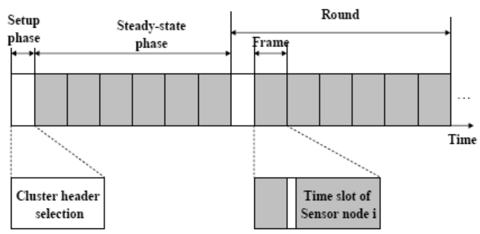

Fig. 1 Time line showing operation of LEACH

In [7] an enhancement over the LEACH protocol was proposed. The protocol, called LEACH-C, uses a centralized clustering algorithm and the same steady-state phase as LEACH. During the setup phase of LEACH-C, each node sends information about its current location (possibly determined using position finding system) and residual energy level to the BS. In addition to determining good clusters, BS need to ensure that the energy load is evenly distributed among all the nodes. To do this, BS computes the average node energy and determines which node has energy below this average. LEACH-C does not support the scalability of wireless microsensor networks since this requires the BS to solve the NP-hard problem of finding K optimal clusters which is not feasible for a network with thousand of nodes.

III. Preliminaries

A. Radio Energy Dissipation Model

We assume a simple model for the radio hardware energy dissipation where the transmitter dissipates energy to run the radio electronics and the power amplifier, and the receiver dissipates energy to run the radio electronics, as shown in Fig. 2.

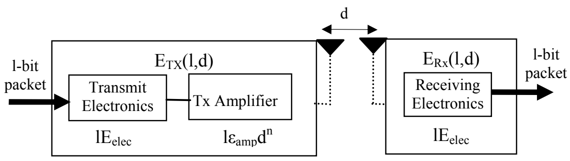

Fig. 2 Radio energy dissipation model

Both the free space (d^2 *power loss*) and the multipath fading (d^4 *power loss*) channel models are used depending on the distance between the transmitter and receiver [13]. Power control can be used to invert this loss by appropriately setting the power amplifier if the distance is less than a threshold, the free space (f_s) model is used; otherwise, the multipath (mp) model is used. Thus, to transmit an *l-bit* message a distance, the radio expends:

$$E_{TX}(l,d) = E_{TX-elec}(l) + E_{TX-amp}(l,d)$$
$$= \begin{cases} lE_{elec} + l\varepsilon_{fs}d^2, d < d_0 \\ lE_{elec} + l\varepsilon_{mp}d^4, d > d_0 \end{cases} \quad (2)$$

and to receive this message, the radio expends:

$$E_{Rx}(l) = E_{Rx-elec}(l) = E_{elec} \quad (3)$$

The electronics energy, E_{elec}, depends on factors such as the digital coding, modulation, filtering, and spreading of the signal whereas the amplifier energy, $\varepsilon_{fs}d^2$ or $\varepsilon_{mp}d^4$ depends on the distance to the receiver and the acceptable bit-error rate.

B. *Optimum Number of Clusters*

According to the radio energy model described previously, in [7] the optimum number of clusters k_{opt} for a cluster-based network that uses *LEACH* communication protocol, and contains N sensor nodes distributed uniformly in an $M * M$ region has been calculated as:

$$k_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}} \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \frac{M}{d_{toBS}^2}. \quad (4)$$

Where, d_{toBS} is the distance from the cluster-head node to the *BS*. Substituting minimum and maximum values of d_{toBS}, the upper bound and lower bound of the desired number of clusters can be obtained. In this interval, k_{opt} will be selected according to: 1) average energy dissipation per round; 2) number of data packets received at the *BS* per time or per energy which determines the network's quality; the more data the *BS* receives, the more accurate its view of the remote environment will be.

IV. Proposed Protocol

A potential problem with *LEACH* is that all cluster-heads send the compressed data to the *BS* directly. If all sensor nodes are pervasive in a large area, some clusters are far from the *BS* and others are close to the *BS*. This can lead to great difference between the transmission energy dissipations that the nodes use to transmit data to the *BS*. The radio transmission energy dissipation includes two parts of radio electronics energy and power amplifier energy. Generally the amplifier energy required for a successful transmission is much larger than the radio electronics energy and dominates the transmission energy dissipation. According to the free space channel model, the minimum required amplifier energy is proportional to the square of the distance from the transmitter to the destined receiver ($E_{Tx-amp} \propto d^2$) [11]. So the transmission energy consumption will increase greatly as the transmission distance rises. It means that the CHs far from the *BS* must use much more energy to send the data to the *BS* than those close to the *BS*. Therefore after the network operates for some rounds there will be considerable difference between the energy consumption of the nodes near the *BS* and that of the nodes far from the *BS*. We assume that all nodes begin at the same energy storage. The nodes far from the *BS* will use up their energy before those near the *BS*. As a result the network will be partitioned into regions with live nodes and dead nodes and the performance of the network will decline. The second problem of LEACH is that in this protocol nodes are absolutely chosen accidentally. Because cluster heading consumes a lot of energy from a node, if a node which is chosen has a few energies, this residual energy is finished faster and node dies. This matter causes to the removal of balance of the network's energy load.

To solve the preceding problems, we propose a novel protocol. This protocol considers the residual energy and distance from the *BS* of each node in the cluster-head selecting process, hence the nodes with the less energy than the other nodes and the nodes with more distance from the *BS* have the smallest chance to be selected as a cluster-head for current round. Through this we ensure that a great difference between energy levels of a near node and a far node would not occur. In this protocol, we divide the whole of the network's terrain into concentric circular segments around the *BS*, and the number of cluster-heads in each segment is different from the other segments in terms of distance from the *BS*. In closer segments the probability of becoming CHs is more than distant segments and thus the number of cluster-heads in these segments is more, on the other hand between each segment's nodes, those who have more energy have the stronger possibility for becoming CH. it is assumed that nodes are aware of their approximate distance from the BS, so that the sensor nodes can guess the segment they belong. In [17], signal strength parameter has been used for approximating the distance parameter. Assuming that the innermost segment has the lowest index, in the segment j, node i may become a cluster-head at round r (which starts at time t) with below threshold:

$$T(n) = \frac{p}{1 - p\left(r \bmod \frac{1}{p}\right)} + \left(\frac{m+1}{2} - j\right) * \left[\left(\frac{E_{n-curr}}{E_{n-\max}}\right)^{\left(\frac{m+1}{2} - j\right)} + \left(\frac{r_s}{epoch}\right)\right] \quad (5)$$

In this equation j is the segment number, m is the number of total segment in the network field, E_{n-curr} and E_{n-max} are current energy and initial energy of each node respectively, r_s is the number of consecutive rounds (in each epoch)in which a node has not been cluster-head. Thus, the chance of near to *BS* and high energy nodes to become CH increases because of a higher threshold. Additionally, r_s will be reset to *0* when a node becomes CH or when r_s reaches the value *(epoch-1)*.

V. Simulation Results

In this section, we evaluate the performance of the proposed approach through the simulations. A simulator is designed and implemented in *MATLAB* in order to investigate the efficiency of the mentioned protocols. We compare the proposed approach with *LEACH*. In our experiments, we consider two network topologies. The simulation parameters used in each experiment are shown in Table I. For the first experiment nodes are randomly distributed between *(x = 0, y = 0)* and *(x = 350, y = 350)* with the BS at location *(x =175, y = 175)*. Fig. 3 shows the total number of nodes that remain alive over simulation time of 1100 rounds. It can be seen that nodes remain alive for a longer time in *EDBC* than *LEACH*. Note that further increasing of the number of segments from three does not improve the network lifetime considerably, so we did not increase the number of segments further. Fig. 4 shows the total energy consumption of the network over simulation time. Based on simulation results, we find that an energy saving up to 15% is obtainable. Using two metrics, First Node Dies (FND) and Half of the Nodes Alive (HNA) proposed in [16], we exactly compare *LEACH* with *EDBC* in terms of network lifetime. Fig. 5 illustrates that using our scheme can increase the lifetime of a microsensor network by 94% for FND and more than 6% for HNA.

TABLE I
PARAMETERS VALUES USED IN THE SIMULATION

Parameters	Experiment 1 (BS is inside)	Experiment 2 (BS is outside)
Network Span	(0,0) to (350,350)	(0,0) to (200,200)
N	200	200
do	87.7m	87.7m
Bs Position	(175,175)	(100,300)
E_{elec}	50 nJ/bit	50 nJ/bit
ε_{fs}	$10 pJ / bit / m^2$	$10 pJ / bit / m^2$
ε_{mp}	$0.0013 pJ / bit / m^4$	$0.0013 pJ / bit / m^4$
Number of Time Frames Per Round	1	1
Round Duration Time	20_s	20_s
E_{DA}	$5nJ / bit / signal$	$5nJ / bit / signal$
Initial Energy of Each Node	$0.5J$	$0.5J$
Packet Size	500 bytes	500 bytes
Number of Segments	3	3

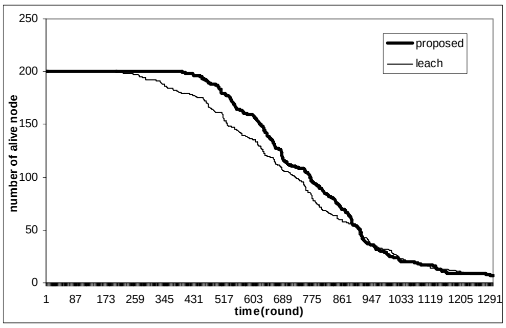

Fig. 3 System lifetime using LEACH and our scheme in the first experiment

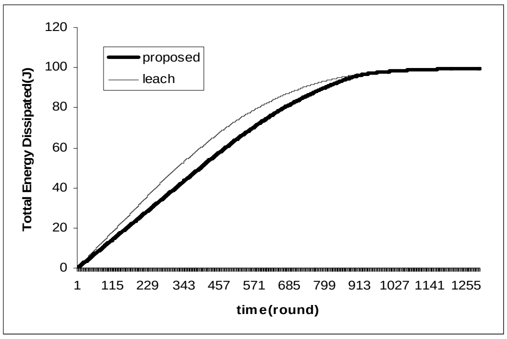

Fig. 4 Total energy dissipated in LEACH and our scheme in the first experiment

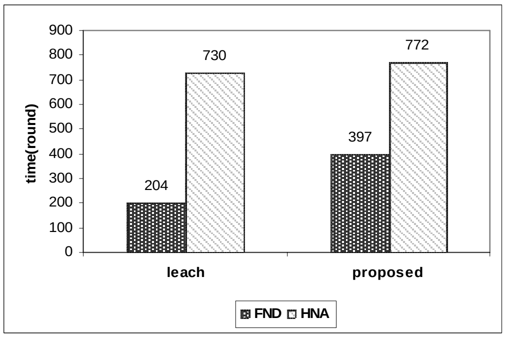

Fig. 5 Comparison of network lifetime using metrics FND and HNA between leach and our scheme in the first experiment

For the second experiment nodes are randomly distributed between *(x = 0, y = 0)* and *(x = 200, y = 200)* with the BS at location *(x =100, y = 300)*. The results of similar simulations to the first experiment for simulation time of 1000 rounds are depicted in Fig. 6 to Fig. 8.

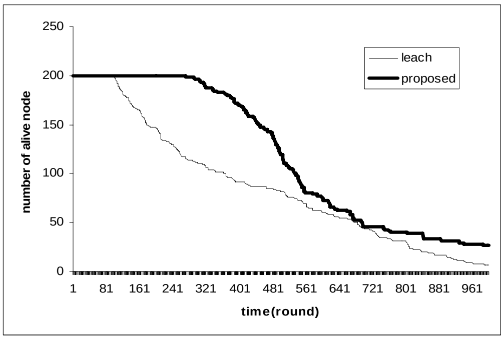

Fig. 6 System lifetime using LEACH and our scheme in the second experiment

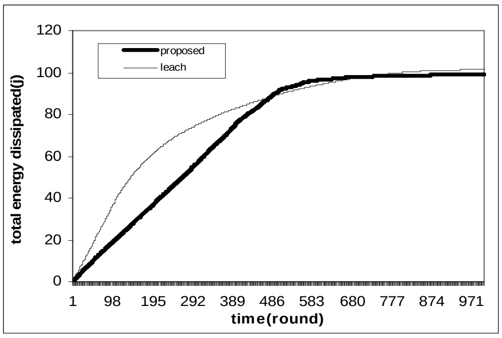

Fig. 7 Total energy dissipated in LEACH and our scheme in the second experiment

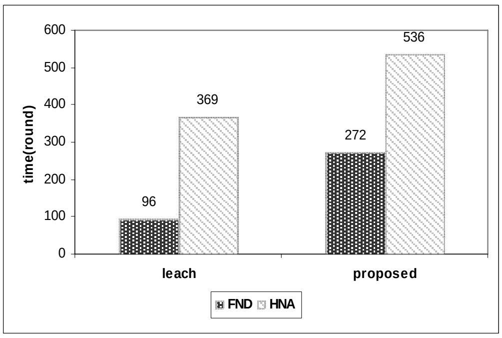

Fig. 8 Comparison of network lifetime using metrics FND and HNA between leach and our scheme in the second experiment

VI. Conclusion and Discussion

In this paper, we have presented *EDBC*, an energy efficient clustering method for WSNs and compared it to the *LEACH* protocol. Results from our simulations show that *EDBC* provides better performance for energy efficiency and network lifetime. However our protocol can be classified as a protocol with continuous data transfer just like *LEACH*, which in its general form is intended for static networks. With some modifications, *EDBC* can handle networks with some mobile nodes. Our protocol can still be improved further. For example, multi-hop routing algorithm can be implemented for all nodes in the network. This means that when a cluster-head has a packet to send to the *BS*, it would route the packet using all nodes including both cluster-heads and members to find the optimal route.

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