Enhanced LEACH Protocol for Wireless Sensor Networks

A.Koucheryavy[1], Ahmed Salim[2], and Walid Osamy[3]

[1] St. Petersburg University of Telecommunication,
akouch@mail.ru
[2] Mathematics Dept.,Fac. of Sci.,
Univ. of Zagazig,
Zagazig, Egypt
a.salim@zu.edu.eg
[3] CS Dept.,Fac. of CS and Informatics,
Univ. of Benha,
Benha, Egypt
walid.osamy@fci.bu.edu.eg

Abstract. Wireless sensor networks (WSNs) are composed of many low cost, low power devices with sensing, local processing and wireless communication capabilities. Minimizing energy dissipation and maximizing network lifetime are important issues in the design of routing protocols for sensor networks. In this paper, the cluster routing protocol LEACH (Low-Energy Adaptive Clustering Hierarchy) is considered and improved. We propose a clustering routing protocol named Enhanced LEACH, which extend LEACH protocol by balancing the energy consumption in the network. The simulation results show that Enhanced LEACH outperforms LEACH in terms of network lifetime and power consumption minimization.

Keywords: Wireless sensor networks, LEACH, Enhanced LEACH

1 Introduction

The vast advancements in technology in general and in wireless communications have specifically give us the ability to mass-produce small, low-cost sensors that can connect to each other wirelessly. The sensors once deployed, whether in a random or a pre-engineered way, will connect to each other and form a wireless sensor network (WSN), which are made of a large number of sensors deployed in a certain area. The sensors would transform physical data into a form that would make it easier for the user to understand. WSN technology is growing rapidly, becoming cheaper and easier to afford, and allowing different kinds of application usage of such networks. WSNs can be used for a wide variety of applications dealing with monitoring (health environments, seismic, etc.), control (object detection and tracking), and surveillance (battlefield surveillance) [6, 7, 3, 4]. In WSNs, the sensor nodes are often grouped into individual disjoint sets called a cluster, clustering is used in WSNs, as it provides network scalability, resource sharing and efficient use of constrained resources that gives network topology stability and energy saving attributes. Clustering schemes offer reduced communication overheads, and efficient resource allocations thus decreasing the overall energy consumption and reducing the interferences among sensor nodes. The basic idea of clustering routing [5, 10] is to use the information aggregation mechanism in the cluster head to reduce the amount of data transmission, thereby, reduce the energy dissipation in communication and in turn achieve the purpose of saving energy of the sensor nodes. In the clustering routing algorithms for wireless networks, LEACH (low-energy adaptive clustering hierarchy)[8, 9] is considered as the most popular routing protocol that use cluster based routing in order to minimize the energy consumption. LEACH was one of the first major improvements on conventional clustering approaches such as MTE (Minimum-Transmission-Energy) or direct-transmission which do not lead to even energy dissipation throughout a network in wireless sensor networks. In this paper we propose an enhancement on the LEACH Protocol that further enhance the power consumption, simulation results bring out that our protocol outperforms LEACH protocol in terms of network life time.

The rest of the paper is organized as follows: Section 2 briefly review related work. Our problem formulation is covered in section 3. In section 4, we introduce our approach to carry out the proposed problem. The simulation of our approach is presented in section 5. In section 6, we conclude our work.

2 Related Research

The limited energy resources of sensor nodes pose challenging issues on the development of routing protocols for WSN. Introducing clustering into the network's topology reduces number of transmissions in the network. It also provides energy efficiency as cluster heads aggregate the data's from its cluster members, thereby reduce duplication of transmission and enhance the network lifetime.

Heinzelman, et.al [8, 9] introduced a clustering algorithm for sensor networks, called Low Energy Adaptive Clustering Hierarchy (LEACH). LEACH forms clusters by using a distributed algorithm, where nodes make autonomous decisions without any centralized control. LEACH arranges the nodes in the network into clusters and chooses one of them as the cluster head(CH), as shown in figure 1.

The operation of LEACH is divided into rounds. Each round begins with a setup phase when the clusters are organized, followed by a steady-state phase when data are transferred from the nodes to the cluster head and on to the Base Station (BS).

In setup phase, all sensor nodes select a cluster head by threshold $T(n)$ in equation 1. The threshold value depends upon the desired percentage (p) to become a cluster head, the current round r, and the set of nodes that have not become the cluster-head in the last $\frac{1}{p}$ rounds, which is denoted by G.

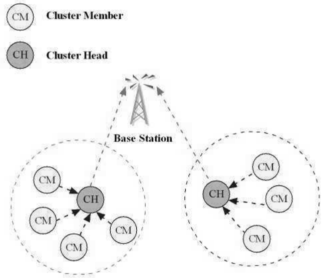

Fig. 1. Illustration of LEACH Protocol

$$T(n) = \{ \begin{matrix} \frac{p}{1-p(rmode\frac{1}{p})} & n \in G \\ 0 & otherwise \end{matrix} \tag{1}$$

Each node want to be a cluster head chooses a value, between 0 and 1. If this random number is less than the threshold value, $T(n)$, then the node becomes cluster head for the current round. After that, elected CH broadcasts an advertisement message to the rest of the nodes in the network to invite them to join their clusters.On the basis of strength of the advertisement signal, the non-cluster head nodes decide to join the clusters.

The non-cluster head nodes inform their respective cluster heads that they will be under their cluster by sending an acknowledgement message. After receiving the acknowledgement message, depending upon the number of nodes under their cluster, the cluster heads create a TDMA schedule and assigns each node a time slot in which it can transmit the sensed data. The TDMA schedule is broadcasted to all the cluster members.

In steady-state phase, the operation is divided into frames (a frame is the interval during which each regular node sends the sensed data to the cluster head [2]). The nodes send their data to the cluster head at most once per frame during their allocated transmission slot. The duration of each slot in which a node transmits data is constant, so the time to send a frame of data depends on the number of nodes in the cluster. Figure 2 shows the time line for one round of LEACH. To reduce energy consumption, each non-cluster head node uses power control to set the amount of transmit power based on the received strength of the cluster head advertisement. Furthermore, the radio of each cluster member node is turned off until its allocated transmission time. The cluster head node must keep its receiver on to receive all the data from the nodes in the cluster. When all the data has been received, the cluster head node sends it to the base station

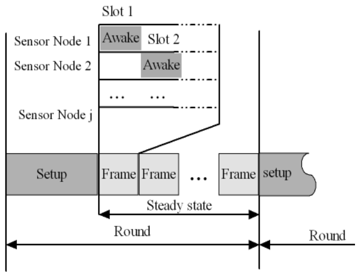

Fig. 2. One round of LEACH operation

after performs data aggregation to enhance the common signal and reduce the uncorrelated noise among the signals.

In [15], Zytoune et al. present a Stochastic Low Energy Adaptive Clustering Hierarchy protocol(SLEACH), which outperforms the LEACH when the interesting collected data is the minimum or the maximum value in an area. SLEACH uses the same method proposed in LEACH for forming clusters. Once the clusters are formed, the cluster head broadcasts in its cluster a data message containing its measurement assuming the pertinent value. Only the nodes, having most significant data, send their messages towards the cluster-head.

In [11], the authors extend SLEACH algorithm by modifying the probability of each node to become cluster-head based on its required energy to transmit to the sink. Their contribution consists in rotation selection of cluster heads considering the remoteness of the nodes to the sink, and the network nodes residual energy. In [12], the authors proposed an algorithm called TB-LEACH which is an improvement of LEACH. TB-LEACH constructs the cluster by using an algorithm based random-timer, which doesn't require any global information. The work described in [14] proposed Variable-Round LEACH (VR-LEACH). VR-LEACH changes the round time according to the residual energy of the cluster head at the beginning of the round, the energy cost in every frame and the constants λ. In VR-LEACH a constant value for λ and the frame time μ are determined each round time, where the values of λ, and μ experimentally defined. The work in [13] proposed Energy-LEACH (E-LEACH) protocol which is an improvement of LEACH. E-LEACH improves the choice method of the cluster head, makes some nodes which have more residual energy as cluster heads in next round. The main difference between our work and [11, 12, 14, 13] is that our work provides energy consumption balancing over all sensor nodes in network by rotating the aggregation processes that occurs through rounds and inside each cluster according to the work load in each frame.

3 Problem formulation

In LEACH protocol, the role of a member node in the cluster is to sense the surrounding environment and transmit the sensed data to a cluster head. On the other hand, the cluster head node aggregates and sends the received data to the BS, which drains out more energy of the cluster head as compared to the other nodes. This operation will be repeated each time frame which leads to energy gap between the cluster heads and the member nodes.

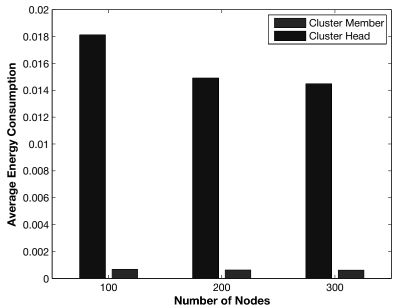

Fig. 3. Average Energy consumption at cluster head nodes and cluster member nodes

For more clarity, consider figure 3, where we used a 100-node network where nodes were randomly distributed between (x=0,y=0) and (x=200, y=200) with base station at location (x=50, y=175). In order to measure the energy dissipation of sensor nodes, we use the same energy parameters and radio model as discussed in [8]. From figure 3, it can be noticed that cluster head nodes have higher average energy consumption rate than cluster member nodes, which reflects a big energy gap between the cluster head and the member node during managing clustering. In this paper, our main goal is to reduce the gap between cluster heads and cluster members and evenly distributing energy consumption over all sensor nodes.

4 Enhanced LEACH

Algorithm 1 Steady phase

for each frame f in round r **do**
  for each cluster member cm_i **do**
    if $cm_i.Timeslot = TRUE$ **then**
      Transmit data to aggregator node $cm_{aggregator}$
    else
      $cm_i.SleepMode = TRUE$;
    end if
  end for
  if $cm_{aggregator}.Timeslot = TRUE$ **then**
    Transmit aggregated data to base station
  end if
end for

In this section, we describe Enhanced LEACH which improves the energy distribution between sensor nodes in each round and prolong the network lifetime. The implementation process of Enhanced LEACH is divided into rounds and each round is divided into three phases, Setup phase, Pre-Steady phase and Steady State phase; each sensor knows when each round starts using a synchronized clock. Figure 4 shows the time line for one round of Enhanced LEACH.

Algorithm 2 GetAggregator

Input: round number r, number of frames $NServedFrames$ and list of nodes M;
Output: node $cm_{aggregator}$ that can works as aggregator node and null if not exist.

repeat
  $count$=number of items in the list M
  { $M[i]$ is the list item number i}
  $cm_{aggregator} = M$[r mod count]
  if $(cm_{aggregator}.NAggregator - NServedFrames) > 0$ **then**
    decrease $cm_{aggregator}.NAggregator$ by $NServedFrames$
    return $cm_{aggregator}$
  else
    remove from the list M the item with index $r \, mod \, count$
  end if
until $count$=0
return NULL

4.1 Setup phase

The setup phase operation of Enhanced LEACH is as the setup phase operation of LEACH. Enhanced LEACH starts with the cluster setup phase. During this setup phase the cluster head nodes are randomly elected from all the sensor nodes and several clusters are constructed dynamically.

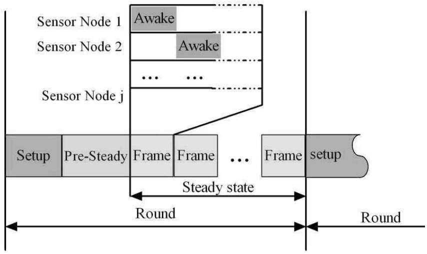

Fig. 4. One round of Enhanced LEACH operation

4.2 Pre-Steady phase

The main idea of this phase is to calculate the cluster workload (which include aggregate the sensed data from cluster members and send the aggregated data to the base station) in one frame, then try to elect cluster member node that can handle the aggregation processes through all frames in the round. If not exist such a node, try to elect cluster member nodes that can handle the aggregation processes for each one frame in the round and the cluster head will handle the aggregation process for frames that there are no aggregator nodes for them.

In this phase, each cluster head CH executes the following steps:

1. Calculate the number of times (NAggregator) each cluster member node (cm_i) can work as aggregator node according to the remaining energy ($cm_i.E_{remaining}$) of cm_i and the energy cost ($cm_i.E_{frame}$) that cm_i will consumed during one frame to handle the aggregation processes (Algorithm 3, Lines 11-14).
2. Elect aggregator node for all frames in the current round by executing algorithm 2. Given the cluster members list M, the number of frames (NServeFrames) that need to serve by aggregator node and the current round number, algorithm 2 work by these parameters as follows:
   – Elect a sensor node from the list M and check if the elected node (say $cm_{aggregator}$)can serve and handle the aggregation process in these frames or not.
   – If $cm_{aggregator}$ can serve the aggregation process in these frames, decrease NAggregator by NServeFrames and return $cm_{aggregator}$.
   – If $cm_{aggregator}$ can not serve the aggregation process in these frames, repeated the same steps and do not consider the previous elected node in the election processes.

Algorithm 3 PreSteady phase

$G_{CM}(ch)$: List of cluster member nodes of cluster head ch
$G_{aggregators}(ch) = \phi$: List of cluster members that work as aggregator nodes indexed by frame number.
r : Current round
$Nframes$:Number of frames per round
$cm_i.E_1$: Consumed energy for cluster member cm_i due to received data from others cluster member nodes in $G_{CM}(ch)$
$cm_i.E_2$: Consumed energy for cluster member node cm_i due to send data to BS
$cm_i.Eremaining$: Remaining energy for cluster member node cm_i.
$cm_i.E_{frame}$: Total consumed energy per frame for cluster member node cm_i to work as aggregator node.
$cm_i.NAggregator$:Number of times that can cluster member node cm_i works as aggregator node.
for each $ch \in G_{CH}$ **do**
    for each node $cm_i \in G_{CM}(ch)$ **do**
        $cm_i.E_{frame} = cm_i.E_1 + cm_i.E_2$
        $cm_i.NAggregator = \lfloor \frac{cm_i.Eremaining}{cm_i.E_{frame}} \rfloor$
    end for
    $cm_{aggregator} = GetAggregator(r, Nframes, G_{CM}(ch))$
    if $cm_{aggregator} \neq NULL$ **then**
        for $f = 1 \rightarrow Nframes$ **do**
            Add $cm_{aggregator}$ to $G_{aggregators}(ch)$
            $f = f + 1$
        end for
    else
        for $f = 1 \rightarrow Nframes$ **do**
            $cm_{aggregator} = GetAggregatorNode(f, 1, G_{CM}(ch))$
            if $cm_{aggregator} \neq NULL$ **then**
                Add $cm_{aggregator}$ to $G_{aggregators}(ch)$
            else
                $cm_{aggregator} = ch$
                Add $cm_{aggregator}$ to $G_{aggregators}(ch)$
            end if
            $f = f + 1$
        end for
    end if
    Broadcast TDMA Schedule along with $G_{aggregators}(ch)$ list to cluster members.
end for

- Return NULL, if there is no node can serve the aggregation processes in these frames.

3. If the returned $cm_{aggregator}$ is not NULL, assign the $cm_{aggregator}$ to serve each frame in the round by adding $cm_{aggregator}$ to the list of aggregators $G_{aggregators}(ch)$ (Algorithm 3, Lines 16-20). If the returned cm_i is NULL, do the following:
   - Elect the aggregator node that serve only one frame in the round by executing algorithm 2. Given the cluster members list M, the number of frames that need to serve by aggregator node is one (NServeFrames=1) and the frame number (f) (Algorithm 3, Line 23).
   - If returned value is NULL , assign the ch to serve the aggregation process for this frame. Otherwise, assign the returned aggregator node $cm_{aggregator}$ to serve current frame(Algorithm 3, Lines 24-28).
4. Broadcast the TDMA schedule and the list of aggregators $G_{aggregators}(ch)$(item number one in the list will serve frame number one in the round) to all cluster members

By the end of this phase, sensor nodes in each time frame are divided into two categories: cluster members and cluster heads.

Cluster Members: These sensor nodes sense the environment and transmit the results to their aggregator nodes. Cluster member sensor nodes are divided into two categories; sensing sensor nodes that do the sensing tasks and aggregator sensor nodes that aggregate data from cluster members and assist cluster head nodes by sending the aggregated data to base station.

Cluster Heads (CH): These sensor nodes manage and determine the schedule information in their cluster. The selected CH perform the following tasks:

- Determine which node work as aggregator node in each frame.
- Create a $TDMA$ schedule and assign to each node a time slot in which it can transmit the sensed data.
- Broadcasts the $TDMA$ schedule and the aggregators list to all the cluster members.
- Maintains and manage the cluster.
- Aggregate sensed data from cluster members in absence of aggregator nodes.

The pseudocode of this phase is given in Algorithm 3.

4.3 Steady State phase

In Steady State phase, the operation is divided into frames, in each frame, cluster member nodes send their data to the aggregation node $n_{aggregator}$ according to their time slots. The aggregation node must keep its receiver on to receive all the data from the nodes in the cluster. When all the data has been received, the aggregation node sends it to the base station after performs data aggregation (see Algorithm 1).

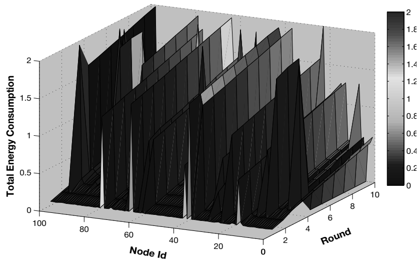

Fig. 5. Energy consumption of LEACH

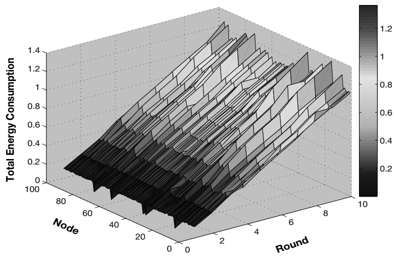

Fig. 6. Energy consumption of Enhanced LEACH

5 Simulation results

A simulator have been implemented in C#.NET language to evaluate the performance of our proposed algorithm. MATLAB was used for the plotting the graphs. In our simulation, 100 sensor nodes are deployed in a region of size $200m \times 200m$ at random on a two dimensional plane and are uniformly distributed with base station at location (x=50, y=175). In order to measure the energy consumption of sensor nodes, we use the same energy parameters and radio model as discussed in [8], wherein energy consumption is mainly divided into two parts: receiving and transmitting messages. The transmission energy consumption needs additional energy to amplify the signal depending on the distance to the destination. Thus, to transmit a k-bit message a distance d, the

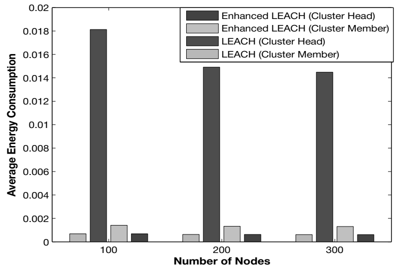

Fig. 7. Average Energy consumption at cluster head nodes and cluster member nodes for Enhanced LEACH and LEACH

radio power consumption will be,

$$E_{Tx}(k,d) = \{ \begin{matrix} kE_{elec} + k\epsilon_{fs}d^2 \ d < d_0 \\ kE_{elec} + k\epsilon_{mp}d^4 \ d \geq d_0 \end{matrix} \quad (2)$$

and to receive this message, the radio expends will be

$$E_{Rx}(k) = k * E_{elec} \quad (3)$$

Simulated model parameters are set as: $E_{elec} = 50nJ/bit$, $\epsilon_{fs} = 10pJ/bit/m^2$, $\epsilon_{mp} = \frac{13}{10000}pJ/bit/m^4$,$d_0 = \sqrt{\epsilon_{fs}/\epsilon_{mp}}$, and the initial energy per node= $2J$.

We are use the following performance metrics to indicate the performance of clustering protocols.

- Network lifetime: this is the time interval from the start of operation (of the sensor network) until the death of the first alive node.
- Energy consumption: is measured by the total number of the network energy dissipation.

Figures 6 and 5 show the energy consumption of Enhanced LEACH compared with that of LEACH. Figure 5 shows that the distribution of consumed energy over all nodes in LEACH is irregular compared with the distribution of consumed energy over all nodes in Enhanced LEACH (in figure 6), it is notice that there are balance in the the distribution of consumed energy achieved by Enhanced LEACH. From Figures 6 and 5 it is noticed that the increase rate of energy consumption of Enhanced LEACH is much lower than the rate of LEACH and it is obvious that in Enhanced LEACH the energy consumption evenly distributed over all sensor nodes.

Figure 8 shows the lifetime for Enhanced LEACH and LEACH. In LEACH, the first node died earlier than Enhanced LEACH. As a result the network life time in Enhanced LEACH is increased compared to LEACH.

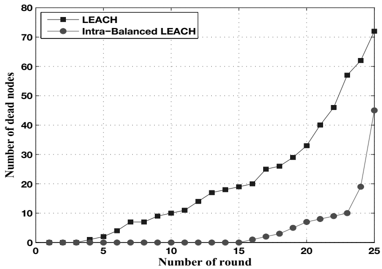

Fig. 8. Network life time

Figure 7 shows that by using Enhanced LEACH, the cluster head nodes and cluster member nodes approximately have the same average energy consumption rate, which reflects a distribution of energy consumption over all sensor nodes compare with LEACH algorithm.

6 Conclusion

In this paper, we improve LEACH, by introducing Enhanced LEACH which is balanced energy consumption protocol for wireless sensor network. Through distributing the cluster load overhead over the cluster members, the life time of the entire network extended compared with LEACH protocol. Our simulation results show that Enhanced LEACH outperformed LEACH in terms of the network lifetime and balanced energy consumption.

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