Hierarchical Routing Approach-Based Energy Optimization in Wireless Sensor Networks

Hania Aoudia, Youcef Touati, Arab Ali-Cherif and Patrick Greussay
Computer Science Lab, LIASD
University of Paris 8
2 rue de la Liberté
93526 Saint-Denis, France
(+33) 1 49 40 64 04
{hania; touati; aa; pg}@ai.univ-paris8.fr

ABSTRACT
We propose a critical improvement of the LEACH (Low-Energy Adaptive Clustering Hierarchy) routing protocol for the optimization of the energy consumption as well as memory occupation of Wireless Sensor Network (WSN). Our protocol LEACH-M uses a cascade of clustering algorithms, every step of which chooses the next one. We expect at best an improvement of 5% of energy consumption and since the lifetime of the application is itself improved the amount of data routed is improved in the same amount. Of course, testing our approach using it along a comparative study with the standard LEACH confirms our expectation.

Categories and Subject Descriptors
C.2.2 [Networks Protocols]: Routing protocols; Protocol verification.

General Terms
Algorithms, Performance, Experimentation.

Keywords
Routing protocol, energy consumption, clustering

1. INTRODUCTION
WSN implementation has become increasingly important for performing potential applications for variety of fields, including medical monitoring, military operations, rescue missions, climate change, and so on [1-4]. For such applications, routing protocols are required in order to insure an efficient communication by transmitting data between sensor nodes and the base station (BS). In this context, routing methods have been widely proposed. These methods can be classified as proactive, reactive and hybrid, based on their operating mode and type of applications. In this paper, we are interested by proactive protocols. The most studied one is LEACH, which is the first hierarchical cluster-based routing protocol for WSN classifying the nodes into clusters [5-6]. In each cluster, a coordinator node with an extra privilege called Cluster Head (CH) is responsible for creating and manipulating messages using TDMA schedule and sending aggregated data from nodes to the BS according to CDMA. Implementing this protocol increases the network performances in term of energy consumption but suffer from many drawbacks in that CH nodes selection is randomly and not uniformly distributed. Some variants of this protocol have also been developed [7]. Energy-LEACH is a protocol that improves the CH node selection procedure. It makes residual energy of node as the main metric which decides whether the nodes turn into CH or not after the first round. The protocol consists of several rounds. In the first one, every node has the same probability to turn into CH node, that means nodes are randomly selected as CH nodes, in the next rounds, the residual energy of each node is different after one round communication and taken into account for the selection of the CH nodes. That mean nodes have more energy will become a CH nodes rather than nodes with less energy. In Multihop-LEACH protocol, an optimal path between CH node and the BS through other CHs is selected, and the data is transmitted via other CHs playing the role as a relay station [8]. In [9], LEACH-C protocol uses a centralized clustering algorithm and the same steady-state phase as LEACH. It can produce better performance by dispersing the CH nodes throughout the network. To determine good clusters and CH nodes, each node sends information about its current location and residual energy level to the sink. Once the CH nodes and associated clusters are found, the sink broadcasts a message that obtains the cluster head ID for each node. If a CH ID matches its own ID, the node becomes CH otherwise the node determines its TDMA slot for data transmission and goes sleep. In [10], Vice-LEACH protocol consists to elect a vice-CH in a cluster, taking the role of the CH when this latter disappears from the network. By doing this, cluster nodes data will always reach the BS and there’s no need to elect a new CH each time the CH dies. This will extend the overall network life time. These methods are quite efficient, but find promptly their limitations when the density of the networks is large. Indeed, for a hierarchical topology, CHs overloading may force the network to consume more energy and therefore, reducing its lifetime which is one of the major challenges to extend in WSN. Conceiving and developing a routing protocol for WSN requires taking into account considerations related to the problem of energy optimization. In this paper, we propose and study a hierarchical routing protocol LEACH-M based on clustering mechanism which considers both residual energy of sensor nodes, end-to-end delay for routing information and information loss.

This paper is organized as follows: Section 2 presents the basic principles of the proposed hierarchical routing approach LEACH-M. To test the effectiveness of the proposed routing approach, we have conducted in section 3, a comparative study between LEACH-M and a standard routing protocol LEACH. Finally, a conclusion is dressed in section 4.
2. PROPOSED ROUTING PROTOCOL

As it is proposed in [5] and mentioned in [11], our proposed algorithm LEACH-M combines the concept of clustering and hierarchy to achieve energy-efficiency. The network is decomposed into set of clusters wherein nodes organize themselves to become member nodes MNs and transmit their data locally to their cluster heads CHs. After receiving and processing the data, the results will be transmitted to the BS. In this case, the traffic is reduced. However a CH consumes more energy than the MNs. The implementation of LEACH-M is divided into rounds, and each round is made up of a clustering phase, a set-up phase and a steady-state phase.

2.1 Announcement and Clustering Phase

During clustering phase, commonly called advertisement phase, the BS announces a new round in which new clusters are created and each node decides whether or not to become a CH. The decision is based on a probability of election of a given node as a CH and the suggested percentage of CHs (10%). This election can be expressed as follows:

\[
T(n) = \begin{cases} 
  P & \text{if } n \in G \\
  0 & \text{otherwise}
\end{cases}
\]

where \( P \) and \( r \) denote respectively the percentage of nodes wishing to be CH and the iteration of the current round. \( G \) represents the set of nodes that hasn’t been a CH node during the last \( \lceil \sqrt{r} \rceil \) iterations.

A random number between 0 and 1 is assigned to a node \( n \). If the number is less than a threshold \( T(n) \), the node becomes a CH node for the current round and notifies its neighbors of its election.

2.2 Scheduling Phase

Once the clusters are formed for a given round, each CH node associated to a cluster will play a role as a coordinator for processing and transmitting data between MNs and the BS. Thus, it broadcasts an advertisement message to the rest of the nodes. Then, each node decides to belong to a cluster by informing the associated CH that it will be a MN. It depends on the received signal strength emitted by the CHs nodes. Based on the number of nodes in the cluster, the CH node creates a TDMA MAC protocol or schedule each node when it can transmit data by assigning a timeslot. This schedule is broadcasted back to the nodes in the cluster.

2.3 Transmission Phase

Commonly called Steady-state phase, represents the main phase where energy consumption should be optimized. Based on TDMA protocol, MNs send their data to their CH during their allocated transmission timeslot. The CHs nodes will aggregate collected data and transmit them directly or indirectly to the BS. The radio of each non-CH node can be turned off until the node’s allocated transmission time, thus minimizing energy dissipation in these nodes. The CH node must keep its receiver on to receive all the data from the nodes in the cluster. When data are completely received, the CH node performs signal processing functions to compress the data into a single signal. This signal will be transmitted to the BS. Since the BS is far away, this is a high-energy transmission. After all data from all nodes are transmitted to the BS, a new round will start.

Each node incorporates sleep and wakeup tasks leading to optimize energy consumption. In contrast, as it’s described above, a CH node consumes a lot more energy than the member nodes because he’s continuously active. In fact, after the CH node receives the data from all the member nodes, it processes the data, and transmits the processed data to the BS. During this process, energy consumption of different CHs nodes becomes significant leading to limit their operational capabilities in the network.

Contrary to data processing phase, communication phase requires substantial amounts of energy. Thus, energy consumption can be expressed by a model including both transmitter and receiver communications [12]. Transmitting \( k \) bits of data over a distance \( d \), the transmitter consumes:

\[
E_{TX}(k,d) = k \cdot E_{elec} + k \cdot E_{amp} \cdot d^2.
\]

And the energy used to receive \( k \)-bits of data is:

\[
E_{Rx}(k,d) = E_{elec} = k \cdot E_{elec}.
\]

Based on energy model given by (2) and (3), the average energy consumption in each CH node can be computed as follow:

\[
E_{avg} = p_r \cdot E_{elec} + (1 - p_r) \cdot E_{tx}.
\]

where:

\[
E_{tx} = E_{TX}(k,d) + E_{Rx}(k,d).
\]

and,

\[
E_{rx} = E_{Rx}(k,d).
\]

Parameters \( p_r, P \) and \( r \) represent respectively the probability that each node has \( k \) bits of data to be sent and the consumed time for transmitting a byte of data. \( T_{inter} \) and \( T_{intra} \) denote respectively the communication time between CHs nodes and the BS, and the communication time between CHs nodes and MNs during a round.

In the first term of (4), for a given probability \( P \) corresponding to an inter-CH communication phase, all CHs nodes exchange information with the BS with an energy consumption equivalent to \( E_{TX}(k,d) \). The rest of the time \( (T_{inter}/T - k) \) corresponds to the listening time where energy consumption is \( E_{Rx}(T_{inter}/T - k) \). The second term of (4) corresponds to a probability \( (1 - p_r) \) where the CH node does not transmit any data to the BS. He spends all his time for inter-CHs communication in listening mode consuming energy of \( E_{Rx}(T_{inter}/T) \). During intra-CH communication phase, CH node switches to a receive mode consuming \( E_{Rx}(T_{intra}/T) \).

Some assumptions for implementing the proposed routing protocol:

- The network consists of \( n \) homogeneous nodes randomly distributed.
- Energy consumption model is described in (4).
- Collisions avoidance in inter- and intra-CH radio communication is insured respectively by CSMA/CA and TDMA methods.
- The election of a new CH node is computed by the CH of the previous round according to the energy criterion.

The principle of the algorithm operates as follows:

- At first, as in standard protocol LEACH, and via a broadcast message, the BS determines the number of clusters and the probability \( P \) associated to different CHs nodes. The protocol
uses the formulation described in (1). In our case, the number of CHs nodes is around 10% of $n$.

- Each node receiving message from the BS must broadcast it into its neighbors. Each node must generate randomly a number $nb_a$ that must be compared to the probability $P$ determined by the BS. If ($P \leq nb_a$) then the considered node can potentially be a CH, if not, it stands for other messages coming from other CHs nodes. If the node is elected as CH, he informs all his neighbors of his new role by sending an ADV message containing its identifier. Based on the number of nodes in the cluster, the CH node creates a TDMA MAC protocol or schedule telling each node when it can transmit data by assigning a timeslot. This schedule is broadcast back to the nodes in the cluster. Each node decides to belong to a cluster by informing the associated CH that it will be a MN. It depends on the RSS emitted by the CHs nodes.

- Once the clusters formed, each CH node will coordinate the transmission within its own group. Based on a scheduling task, it uses a TDMA method to assign for each NM a timeslot in which the node can transmit its information. Otherwise, NM activates its sleep mode to optimize its energy consumption.

- Different CH nodes will aggregate collected data and transmit them directly or indirectly to the BS according to a CSMA/CA method. Then, they proceed, in a new round, to elect a new CH node according to residual energy.

To evaluate performances of the proposed routing protocol LEACH-M, we have performed a comparative study with a standard routing protocol LEACH. The obtained results are analyzed and discussed in the next section.

End-to-end delays are corresponding to the elapsed time for any data to reach its destination from any source. LEACH-M includes two types of information; intra-and inter-CHs. Based on some assumptions outlined above, data derived from MNs of each cluster moves directly to the corresponding CH-node. Thus, via an inter-CHs communication, aggregated information is transmitted in a single hop to the BS. The more MNs increases, the greatest time of data aggregation is. The larger the network is the more end-to-end delay increases (Fig.2). In fact, when implementing LEACH-M protocol, obtained results are better than those of LEACH standard routing protocol. For a network with 100 nodes, end-to-end delays are around of 99,993[ms] and 102,103[ms] respectively for LEACH and LEACH-M protocols. The same is true for a network with 200 nodes, where end-to-end delays are respectively 100,988[ms] and 103,052[ms] for LEACH and LEACH-M protocols. The gain in term of elapsed time for any data to reach its destination varies between 2% to 5%.

3. RESULTS AND ANALYSIS

In this section, we implement the proposed hierarchical routing protocol LEACH-M, and we compare the obtained results with a standard routing protocol LEACH. In this context, a simulation environment based TOSSIM is selected, and as a development tool, we use NesC object-oriented programming language [13]. Communication part is based on a scheduling policy of data via a radio propagation model called LOSSY. Nodes forming WSN have same characteristics as MICA2 sensor model. They are randomly deployed in the operational environment. LEACH-M performances are evaluated using energy consumption criteria. A number of experiments were performed taking into account the density of the network. We have proposed networks with 50, 100, 150 and 200 nodes. The simulation time is about 300 milliseconds.

Figures 1.a and b show the obtained results concerning the average energy consumption in the network. One can note that the use of resources increases with the density of the network. The obtained results show that LEACH-M performs better than LEACH. They illustrate respectively consumed energies by CHs nodes and NMs. Considering a network with 100 nodes, the average energy consumption using LEACH-M for CHs nodes is approximately 22.7323 joules and 17.2148 joules for the NMs. Thus, we remark that energy consumption is lower in LEACH-M than in LEACH. This can be justified by the fact that the election of new CHs nodes for each new round is directly ensured by the old CHs nodes not by the BS. This procedure of election limits the number of control messages and the overloading of network.

To determine the network ability for processing information, we have computed the number of messages in term of DATA PACKETS exchanged between clusters and the BS (Fig.3).
compared to LEACH. These results also reflect a better resource usage number of packets loss which is strictly less in LEACH-M implementing LEACH-M than LEACH. The same is true for the number of control messages exchanged between different MNs and CH nodes is much lower when applying LEACH-M protocol than LEACH. The obtained results show that the proposed approach gives better performance. We have conducted a comparative study with a standard routing protocol LEACH, where nodes select their membership to a given CH based on their residual energy of sensor nodes, end-to-end delay for routing information and information loss. In contrast to the standard routing protocol LEACH, where nodes select their membership to a given CH only once, in LEACH-M, a node selects the CH node having a highest residual energy by sending a membership request. This election procedure means that during inter-CHs transmission, CH-nodes have sufficient energy to process the data collected from MNs, and then to transmit them to the BS.

Unlike inter-CHs communication, intra-CH communication concerns two phases of communication: communication between CH-nodes and all nodes for establishing their membership to a cluster and communication between CH-nodes and MNs. As it’s illustrated on Figure 3.b, in both cases, applying LEACH and LEACH-M protocols, the number of messages exchanged in intra-CH communication increases according to the network density, but less important for M-LEACH protocol. In a network with 100 nodes, the number of exchanging messages between CH-nodes and MNs is 10273 for LEACH protocol and 5540 for LEACH-M. Thus, comparing these results to those shown in Figure 2, we can conclude that communication phase represents the phase where the network consumes more energy.

4. CONCLUSION

In this paper, we described a new variant of a routing protocol oriented towards a solution to the problem of resources optimization and lifetime extension in WSN. For this purpose, we have proposed and studied a hierarchical protocol called LEACH-M based on clustering mechanism which considers both residual energy of sensor nodes, end-to-end delay for routing information and information loss. In contrast to the standard routing protocol LEACH, where nodes select their membership to a given CH only once, in LEACH-M, a node selects the CH node having a highest residual energy by sending a membership request. This election procedure means that during inter-CHs transmission, CH-nodes have sufficient energy to process the data collected from MNs, and then to transmit them to the BS.

Thus, Figure 3.a shows the number of messages sent by different CH nodes to the BS increases according to the density of the network. Unlike LEACH protocol, the number of inter-CHs messages is more important when applying LEACH-M protocol. For a network with 100 nodes, the number of messages for LEACH and LEACH-M is respectively 41 and 57. For a network with 200 nodes, it is respectively 64 and 81 messages. This means that during inter-CHs transmission, CH-nodes have sufficient residual energy and computing time to achieve aggregation process of data collected from MNs, and then to transmit them to the BS.

Unlike inter-CHs communication, intra-CH communication concerns two phases of communication: communication between CH-nodes and all nodes for establishing their membership to a cluster and communication between CH-nodes and MNs. As it’s illustrated on Figure 3.b, in both cases, applying LEACH and LEACH-M protocols, the number of messages exchanged in intra-CH communication increases according to the network density, but less important for M-LEACH protocol. In a network with 100 nodes, the number of exchanging messages between CH-nodes and MNs is 10273 for LEACH protocol and 5540 for LEACH-M. Thus, comparing these results to those shown in Figure 2, we can conclude that communication phase represents the phase where the network consumes more energy.

optimization in LEACH-M than in LEACH leading finally to increase the lifetime of the network.

5. REFERENCES