Opportunity Coefficient for Cluster-Head Selection in LEACH Protocol

Ben Soh, Mohammed AlZain*, Diego Lozano-Claros and Basanta Adhikari

Department of Computer Science, La Trobe University, Bundoora, Australia

*College of Computer Science, Taif University, Taif, KSA

Abstract

Routing protocols play a pivotal role in the energy management and lifespan of any Wireless Sensor Network. Lower network lifetime has been one of the biggest concerns in LEACH protocol due to dead nodes. The LEACH protocol suffers from uneven energy distribution problem due to random selection of a cluster head. The cluster head has much greater responsibility compared to other non- cluster head nodes and consumes greater energy for its roles. This results in early dead nodes due to energy lost for the role of cluster- head. This study proposes an approach to balance the energy consumption of the LEACH protocol by using a semi-deterministic opportunity coefficient to select the cluster head. This is calculated in each node with the battery energy level and node ID. Ultimately, based on the opportunity cost, cluster head will be selected and broadcasted for which other nodes with higher opportunity cost will agree. It minimizes the chances of nodes with lower battery level being elected as cluster head. Our simulation experiments demonstrate that cluster heads chosen using our proposed algorithm perform better than those using the legacy LEACH protocol.

Key words:

Wireless sensor network, cluster head, battery level, opportunity coefficient, LEACH

1 INTRODUCTION

A wireless sensor network is an intelligent communication system that it is composed by a large number of sensors called nodes which monitor some conditions. These sensors have the ability to communicate either among each other or directly to an external base-station (BS). A greater number of sensors allows for sensing over larger geographical regions with greater accuracy. Basically, each sensor node comprises sensing, processing, transmission, mobilizer, position finding system, and power units (some of these components are optional like the mobilizer) [1].

The nodes can be divided into two types: passive or active. The passive nodes do not have any internal energy source. Thus, they harvest the necessary power from the EM waves, which are radiated from a base station to energize the electronic circuitry. Also, passive nodes usually utilize the backscattering technique to transmit back to the base station. However, the network latency is high and the computational power is limited due to power restrictions.

On the other hand, active nodes use batteries to energize its circuitry. The major reasons of energy consumption for routing in WSNs can be classified as neighborhood discovery, communication and computation [2]. Consequently, the lifetime is limited. Regardless of this issue, active nodes have advantages concerning sensing distance, sensing rate, stability, and additional functions.

The energy preservation becomes the most important factor in deploying any WSN networks due to the battery constrain. As a result, some optimizations of components at the physical layer can improve the overall performance of the system and save battery energy; for example, by having more efficient antennas, better ICs, transmitter and RF design. Nevertheless, it is not sufficient to increase battery lifespan.

As a matter of fact, the routing protocol at Layer 2 between the sink and nodes can provide the most significant improvement to efficiently manage the energy of the network. Routing protocols can save energy by minimizing local information exchange without hampering the routing accuracy. Also, data from multiple nodes can be aggregated into a single packet to decrease the traffic volume [2].

2 BACKGROUND

There are many WSN routing protocol and they can be classified in four main architectures, hierarchical, data-centric, geographical and QoS-based. The hierarchical routing protocols have some advantages over other architectures in terms of scalability and energy consumption. One of the most extensively utilized and studied protocol is the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol. LEACH is a self-organizing, adaptive clustering protocol that uses randomization to distribute the energy load evenly among the sensors in the network. In LEACH,

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the nodes organize themselves into local clusters, with one node acting as the local base station or cluster head [3]. The LEACH topology consists of three hierarchical levels, namely sink/base station, cluster head and common nodes. The cluster head (CH) collects and concatenates the information coming from its neighboring nodes. Then, the CH sends this information to the sink.

Further, the LEACH protocol can be classified as a proactive routing protocol as it utilizes predetermined routes to forward the information. Each node is required to have two separate RF transceivers which operate at different frequencies, power levels and multiple-access protocols such CDMA and TDMA. For instance, the communication between the cluster heads and the sink uses a high-level power and CDMA protocol. Thus, the TDMA protocol is used for the communication between the cluster head and common nodes. The cluster head is responsible for creating and maintaining TDMA schedule [5].

3 MOTIVATION

Nodes with low energy level have the same probability as the ones with higher residual energy levels. This issue unbalances the network as exhausted nodes which become cluster heads are likely to spend much quicker the residual energy and may die when they try to establish a communication with the sink rather than communicate with neighboring nodes. Energy saving can be a key component to increase network lifetime [8].

The main problem of the LEACH protocol is that the cluster heads are elected randomly, so the optimal number and distribution of cluster heads cannot be ensured. The nodes with low remnant energy have the same priority to be a cluster head as the node with high remnant energy. Therefore, those nodes with less remaining energy may be chosen as the cluster heads which will result in that these nodes may die first [4], as detailed below.

A great proportion of energy in LEACH protocol is invested only for cluster heads [6]. All nodes have the same opportunity to become a cluster head once in a round to save energy. It means that a node in a cluster has the probability (denoted by equation (1) in Section 4) to be randomly chosen. LEACH does not appoint a single node in a cluster as cluster head but randomly selects node to be cluster head so that every node could be a cluster head and hence avoid battery depletion on a single node [7]. The likelihood increases by the numbers of rounds. However, the main disadvantage of this approach is that the optimal number of nodes in a cluster and cluster distribution cannot be ensured.

To that end, this paper purposes an improved version of the LEACH protocol. It takes the advantages of an opportunity coefficient to select the cluster head and vice-cluster head using a semi-deterministic approach rather than a random approach. The opportunity coefficient is based on the battery energy level and node ID.

4 PROPOSED ALGORITHM

The rationale behind the proposed algorithm is as follows. The opportunity coefficient (see subsection 4.2.1) for cluster selection in LEACH protocol can be divided into three parts for a better explanation, namely, network requirements, setup and steady phase.

a. Network Requirements

Each node in the network must have the following requirements:

- All can operate at two radio frequencies (F1 and F2). F1 is used between cluster heads and sink and F2 is used by the neighboring nodes in the clusters.
- Each node in the network has a unique ID.
- The ID of nodes can be represented by 1, 2 and 3 bytes.
- The sink/base station may know or not the majority of IDs of the nodes in the network.
- The sink has an unlimited power source.
- All nodes are battery operated. If the battery run out, it means that the node die
- Each node has a microcontroller and memory to process information.
- All nodes have the necessary circuitry to measure the battery voltage.

b. Setup Phase

One of the nodes in each node acts as a cluster head whose prime responsibility is to receive message from base and convey that message to all other nodes [9]. The sink sends a wakeup signal to all nodes in the network using frequency F2 at high transmission power. Then, the nodes turn on the receiving module to listen to the sink. After that, the sink broadcasts a command telling the nodes to check the battery voltage. So, nodes measure and allocate the battery reading onto three levels, namely, High, Medium and Low.

At the same time, the sink generates a pseudorandom binary ID vector (v) from a uniform distribution, $v \in R^n$, where n is bit length. The maximum and minimum values of the distribution are the determined by the ID length. For instance, if the bit-stream length is equal to 8-bit, the distribution range is from 00000001 to 11111111. After the v vector is generated, it is sent to all active nodes using the cluster frequency F2 at high transmission power.

The operating nodes receive the random ID, v, and calculate the opportunity coefficient based on their individual battery level and the similarity between v and own binary ID vector (x), $x \in R^n$.

The opportunity coefficient determines the broadcasting order. It means that a node with the lower opportunity coefficient is the first to advertise itself as a cluster head using frequency F2 at low transmission power. When it occurs, the rest of the nodes in the cluster implicitly agree with this decision without sending any acknowledgement or confirmation since they already know that they have a higher opportunity coefficient value.

The self-proclaim cluster head turns on the receiving RF module at F2 frequency to listen to its neighboring nodes. Then, they use F2 frequency at low transmission power to send information to the cluster head in the same order already determined by the opportunity coefficient. So, the first node that sends the information to the cluster head automatically becomes the vice-cluster head.

4.1 Opportunity coefficient calculation

It represents the likelihood that nodes have to become a cluster head. It is calculated by a battery level prior ity, IDs similarity and the weighted Hamming Distance. Fig. 1 Opportunity coefficient calculation. shows the process.

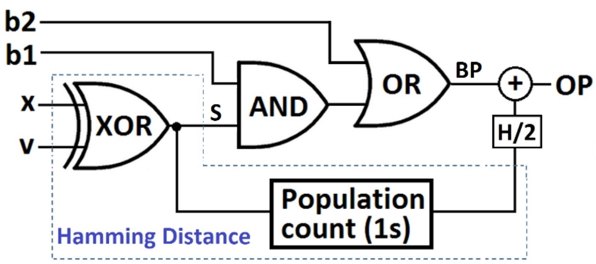

Fig. 1 Opportunity coefficient calculation.

The battery priority (BP) is calculated using the voltage battery reading and the number of bits which are similar between IDs. The BP uses the first 5 LSB digits to reduce the delay and latency time of the network. So, there are three priority levels that they are set using two thresholds (T1 and T2). Also, each one has two fixed binary numbers associated to it, namely, the LSB mask (b1) and penalty (b2).

Table 1: Priority levels

Priority	Voltage Reading	b_1 (Penalty)	b_2 (LBS mask)
Low	$0V < V \leq T1$	00011000	00011111
Medium	$T1 < V \leq T2$	00001100	00001111
High	$T2 < V < Vm$	00000000	00000111

An Exclusive Or logic operation is used to calculate similar bits (S) between the random received ID and own binary vector ID (x), $x \in R^n$. It is within the range of 00000000 and 11111111, the most and least similar respectably.

$$S = (x \oplus v) \quad (1)$$

Then, b1 masks S by using an AND logic operation to get the first 5 LSB digits.

$$f = (b1 \wedge S) \quad (2)$$

After that, the b2 penalizes S by adding 24 for low, 12 for medium and 0 for high battery level.

$$BP = (b2 \vee f) \quad (3)$$

In table 2 can be seen the decimal range and number of states of the battery priority.

Table 2: Battery priority

Priority	BP range	BP states
High	0 – 7	8
Medium	12 – 15	4
Low	24 – 31	8

Separately, the Hamming distance between v, and x is calculated.

$$H = \sum_i |x_i - v_1| \quad (4)$$

The probability that x is equal to v depends on the minimal Hamming distance.

$$P = \frac{1}{N}\sum_i^N (1-\varepsilon)^m \left(\frac{\varepsilon}{\varepsilon-1}\right) \quad (5)$$

Then, H is divided by 2 and rounded down to the next integer. So, the opportunity coefficient (OP) is equal to the equation (6).

$$OP = b2 \vee (b1 \wedge (x \oplus v)) + round\left(\frac{H}{2}\right) \quad (6)$$

In table 3 can be seen the decimal range and number of states of the opportunity coefficient.

Table 3: OP range

Priority	OP range	OP states
High	0 - 10	11
Medium	1 2- 18	7
Low	24 - 34	11

The broadcasting slot time ($Slot$) order can be calculated by multiplying OP by a single slot time duration τ_0.

$$Slot = (OP + 1) * \tau_0 \quad (7)$$

Table 4: Broadcast time slot

OP	0	1	2	3	4	...
Time slot	τ_0	$2\,\tau_0$	$3\,\tau_0$	$4\,\tau_0$	$5\,\tau_0$	...

4.2 Selection of cluster head

The node with the lowest OP value (min $OP = 0$) has the highest priority to broadcast itself as a cluster head. However, if the nodes in a cluster do not listen to a cluster head advertisement during the first time slot, the nodes which has the next lowest OP value ($OP = 1$) can advertise itself as cluster head in the next timeslot. The process repeats until a node with a particular OP value can broadcast itself as a CH. The neighboring nodes agree to be part of a particular cluster by sending a reply with their ID and battery level to the cluster head.

The probability of successful broadcast of a high power node as a cluster head is determined by the following expression:

$$Pb = \frac{1}{(\#\,Thresold+1)(5\ bits)N}\sum_i^N (1-\varepsilon)^m \left(\frac{\varepsilon}{\varepsilon-1}\right) \quad (8)$$

Also, it is important to point out that it could be a collision at any time between two or more nodes within a cluster because they can have the same OP value. There are two situations: one is when a collision occurs between cluster head candidates and another between common nodes.

If cluster head candidates advertise themselves as cluster head at same time, all neighboring nodes detect the collision and go to sleep mode until a new cluster wakes them up. However, the nodes involve in the collision start a random hold on timer and the first node becomes the cluster head, the second becomes the vice-cluster head and the others in common nodes. If two or more common nodes are involved in a collision, they must start the hold timer and transmit again the information to the cluster- head.

c. Steady Phase and Data Transmission

This is the stage where the cluster heads collect data from all other nodes in its cluster and send those data to the base station [10]. By the end of setup phase, all the nodes are grouped into clusters and each cluster has a cluster head. Then it is time for the nodes to send data to their cluster head. In other words, the actual transfer of data from nodes to base station takes place during this phase [11]. A single cluster- head will receive data sensed by all the nodes in its cluster which may create ambiguity. Time division multiple access (TDMA) is used to remove this ambiguity and so the cluster- head can receive data from all the nodes systematically. Typically, only those nodes which sense environmental data send the data to cluster head and will remain in inactive state at other times [12]. According to this scheme, all the nodes in WSN in particular cluster are assigned a time slot where they can send the sensed data to their cluster head [13]. As the characteristics of LEACH, only the nodes which need to transmit data will be active and rest of the nodes will be in sleep phase. However, the cluster head needs to listen to all the nodes and so is active for the entire round which is a node with highest battery in a cluster. Data transmissions in LEACH protocol are divided into rounds and each round involves selecting a cluster head [14]. The proposed algorithm follows the similar procedure where a new cluster head is selected at the beginning on new round. The process moves back to the setup phase and a new cluster is formed which elects a new cluster head based on the energy level of nodes again.

5 RESULTS

A different approach of LEACH based on opportunity coefficient was developed. The calculation of opportunity cost of nodes is shown in figure 1 which primarily involves battery energy level and node ID. MATLAB was used to generate nodes and assign battery level to the nodes. A function that calculates opportunity cost and allocates nodes into cluster was developed. Based on the opportunity cost of nodes on each cluster, the node with lowest opportunity cost would broadcast itself as cluster head.

The figure 2 shows output from one of the rounds. Randomly 12 clusters were created and the dots (o) represent the nodes created which reflect the opportunity cost of the nodes. As an example, for cluster number 8, out of 6 nodes, the node with lowest value of opportunity cost is 50 and hence it broadcasts itself as a cluster head. It applies to all the clusters and each cluster has a cluster head with lowest opportunity cost.

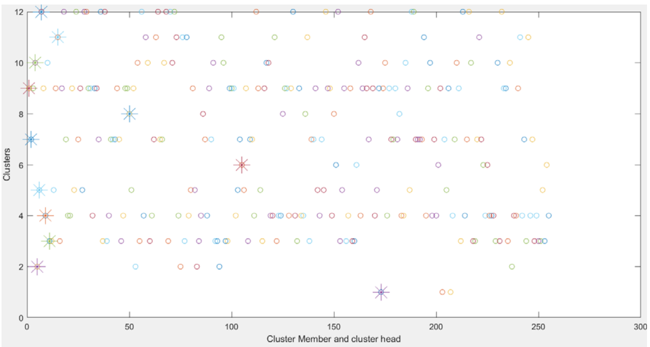

Fig. 2 Selection of cluster head based on opportunity cost based on the proposed algorithm.

In comparison, if normal LEACH protocol is used, it would randomly select cluster head without considering battery level of nodes. The simulation was run for 100 rounds and a graph has been plot based on the frequency of particular node being elected as cluster head. As seen in the figure 3, the node with lowest opportunity coefficient was selected as cluster head for just 4 times whereas node with highest opportunity coefficient was selected 10 times as cluster head. However, one of the non-lowest opportunity coefficient nodes is selected as cluster head for 38 times in 100 runs in our simulation. The data represents the significant chances of node being dead because of energy spend for the role of cluster head.

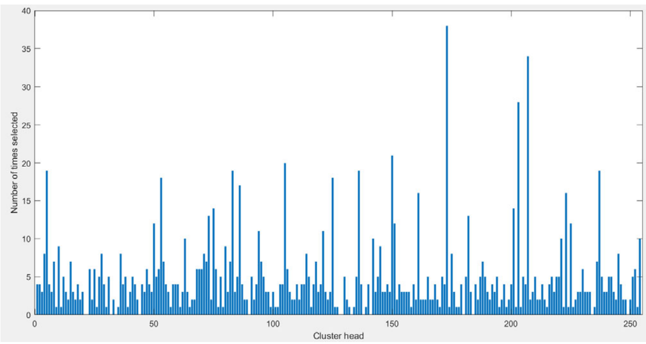

Fig. 3 Frequency of cluster-head selection based on the legacy LEACH protocol.

6 CONCLUSION

This paper is focused on one of the issues in LEACH protocol: dying of the cluster head due to insufficient energy level. Currently, the LEACH protocol randomly chooses cluster head regardless of the energy level and so every node has equal chances of being elected as cluster head. This approach is used because it is better than selecting a single node as cluster head which ultimately leads to dying of that cluster head due to insufficient battery level. However, the concern is when a node that is already low in energy is selected to be a cluster head leading to early dying of such nodes.

However, in our proposed algorithm, once the nodes are grouped into clusters opportunity coefficient is calculated for each node whose process is demonstrated in figure 1. Battery level plays significant role in being elected as cluster head which is a key component used for calculating opportunity coefficient. Due to the involvement of battery level in calculating opportunity coefficient, there are no chances of nodes with least battery level being elected as cluster head. Ultimately, the likeliness of dying of the cluster head due to deficient battery level is lowered.

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