MH-LEACH: A Distributed Algorithm for Multi-Hop Communication in Wireless Sensor Networks

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***Abstract*—Wireless Sensor Networks (WSN) consist in a set of nodes that collect information from the environment and send it to a Base Station that processes the final data. Some challenges in order to minimize the power consumption and maximize the network lifetime in this kind of networks can be found. This paper presents MH-LEACH, an algorithm that permits to establish a multi-hop communication between sensor nodes, which aims to save energy. Using MH-LEACH, a sensor will have options to transmit their data to closer nodes, always sending the collected data to the base station. This proposal was incorporated into the LEACH protocol being evaluated through simulations. The results show improvements in the approach when compared to the original version of LEACH.**

Keywords-Sensor networks; Multi-Hop communication; energy consumption;

I. INTRODUTION

The result of advances in technology and wireless communication, and also sensor networks, has emerged as an important and indispensable tool for the detection of contamination in hazardous environments, habitat monitoring in reserves, enemies inspections in war environments, and other applications [1] [2].

The Wireless Sensor Networks (WSN) are a special kind of ad hoc networks that allow the monitoring of the physical world through small sensors networks densely or sparsely distributed. These networks are composed of hundreds or thousands of sensor nodes with multifunctional low power load, operating autonomously in an environment with limited computational capabilities, and a base station, responsible for receiving data from the sensor nodes.

Currently, WSN are targets of many challenges. One of them is related to the shortage of available energy in sensors, and a large part of the research done today seeks to highlight effective ways to save energy in sensors, making the network lifetime be extended.

The energy used for communication in wireless sensor networks is very high compared to that used for computation, thus it must be carefully used to improve the network lifetime [3]. Routing algorithms based on clustering are widely used to increase the sensor networks lifetime [4] [5] [6].

We present in this article a new algorithm based on clustering that uses a new technique for multihop communication between cluster-heads in order to conserve energy consumed by the network and thereby increase the network lifetime.

This article is organized as follows: Section 2 presents as related work LEACH protocols [7], the LEACH-C [8] and ALEACH [9]. The MH-LEACH is described in Section 3. Section 4 presents the simulations and results. And finally, in Section 5, the conclusion of our work is drawn.

II. RELATED WORK

Saving energy is an extremely important factor in sensor networks. Thus, many routing algorithms aimed in efficient energy consumption have been developed [10] [11] [12]. This section presents some of these algorithms, which are: the LEACH protocol, which is the basis for the development of our work, the LEACH-C and ALEACH.

Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol [7] is a hierarchical protocol for minimizing the power consumption in order to increase the network lifetime. In LEACH, the nodes are organized into clusters, with one node acting as the leader (cluster-head). All non-leaders nodes should transmit their data to the cluster-head, while the cluster-head must receive data from all the cluster members, perform functions of data processing (e.g., data aggregation), and transmit data to the base station.

The LEACH works by rounds. In each round, leader nodes are exchanged in order to distribute the network energy consumption. Two phases compose the rounds: clusters grouping, and communication phase. In the phase of clustering, the choice of leaders is performed through a distributed algorithm, and the source nodes choose to join the nearest cluster-head. In the communication stage, the transfer of data to the base station is made, including aggregation / data fusion by the leaders.

Low-Energy Adaptive Clustering Hierarchy Centralized (LEACH-C) protocol [8] is a variation of LEACH that uses a centralized algorithm for grouping the clusters. During the formation of groups of LEACH-C, each node sends information about its location and energy level to the base station. In order to ensure the distribution of energy to all the nodes in the network, the base station calculates the average energy of the nodes in each round. The cluster-head nodes must have

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the energy level above the average to be chosen, and based on them the base station performs the Simulated Annealing algorithm to determine the best cluster-heads. After finding the clusters and the respective leaders, the base station transmits this information to the nodes of the network. The nodes then transmit the data to the leader of their group, which sends data to the base station.

The Advanced Low-Energy Adaptive Clustering Hierarchy (ALEACH) protocol [9] is an efficient energy routing protocol that considers the level of energy in a sensor node in the election of cluster-heads. As in LEACH, the ALEACH works by rounds and does not need to know the geographic positions of the nodes to elect the cluster-heads.

The Multi-hop LEACH protocol [13] represents an extension of the LEACH to save energy in wireless sensor networks. The purpose of the protocol is send the data to the base station through other intermediate nodes. Like LEACH protocol, Multi-hop LEACH uses the same mechanism for the election of clusters-head. At the stage of data collection, two types of communication are allowed: the inter-cluster communication and intra-cluster communication. In the first communication, the network is divided in clusters. The cluster-head of each cluster receives the data of its member nodes. It performs data aggregation and send the final information to the base station through other nodes. In the intra-cluster communication, the members nodes of the cluster send their data to another members nodes to reach the cluster-head. The protocol works by rounds like LEACH and it selects the path with minimum hops between the clusters-head and the base station.

III. The MH-LEACH Algorithm

The main objective of the algorithm is the establishment of multi-hop communication between clusters-head in a network. The main purpose is to send the packet to the nearest cluster-head that is turned towards the Base Station. With this characteristic, it is intended to decrease the power consumption of the nodes and extend the network lifetime, since the smaller the distance to transmit the lower the consumption is.

A. Energy Consumption Model

As described in [8], a sensor node spends energy according to the model shown in (1) and (3).

The transmission of a message of k bits at a distance d has the following energy consumption:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d) \tag{1}$$

$$E_{Tx}(k,d) = \begin{cases} E_{elec} * k + \epsilon_{fs} * k * d^2, & d < d_0 \\ E_{elec} * k + \epsilon_{mp} * k * d^4, & d \geq d_0 \end{cases} \tag{2}$$

and receiving a message, the sensor has the following consumption:

$$E_{Rx}(k) = E_{Rx-elec}(k) = E_{elec} * k, \tag{3}$$

where:

$E_{Tx-elec}$ = Energy spent in transmission;
$E_{Rx-elec}$ = Energy spent in receiving data;
E_{Tx-amp} = Energy of transmission amplifier;
d_0 = threshold distance, calculated according to the values of E_{elec}, ϵ_{fs} e ϵ_{mp};
ϵ_{fs} = Parameter called free space model (fs), is used if the distance from source to target is less than d_0;
ϵ_{mp} = Parameter called multipath model (mp), used if the distance from source to target is greater than or equal to d_0;
E_{elec} = Energy spent per bit transmitted or received

B. MH-LEACH Operation

In order to understand the proposition, it is important to point out that during the construction of routes between the transmitter (cluster-head) and base station, it is assumed that the network is already clustered and the cluster-heads of each group are already set.

One of the main goals of the algorithm is to find possible routes for a cluster-head (leader) to send a packet using other cluster-heads in order to save its energy. The choice of the next cluster head to get the message must take in account if it has enough energy. Thus, if a cluster-head cannot send a message for another one, this node will try to find another cluster-head based on information contained in its routing table, according to described ahead.

This proposal takes into account the fact that the higher the signal strength of the received packet, i.e., Received Signal Strength Indicator (RSSI), the greater the proximity of the node that sent the message. This information is used in order to build the routing table for each cluster-head.

The MH-LEACH proposes the routes establishment using two phases:

- ***Phase 1:*** The cluster-heads are defined as a part of LEACH algorithm. After that, they broadcast an announcement message and all the cluster-headers in the transmission ratio will take the advantage in order construct their routing table taking in account the level of signal (RSSI) received. So, they organize their early routes containing the closest cluster-heads to send a packet. The base station performs the same procedure as seen in Fig. 1.
- ***Phase 2:*** After that, each leader sends these initial routes (from routing table) to the base station that will check whether a cluster-head can be in the route of another one. After this check, the base station sends their routes back to the nodes.

This procedure is necessary because it needs to create a table of possible routes to a cluster-head. From the intensity of the signal announced, each node keeps a list sorted by proximity of the possible destinations of the packet. As shown in Fig. 2, node 1 has the first choice route the node 2, node 2 to the node 3, and so on. The id (identifier) zero in the table indicates the Base Station. Negative values indicate the signal strength in decibelmiliwatt (dBm).

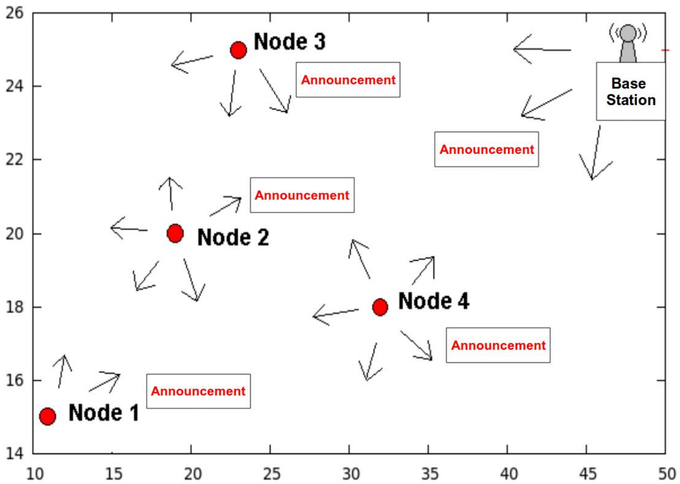

Figure. 1. Cluster-head and base station are identified.

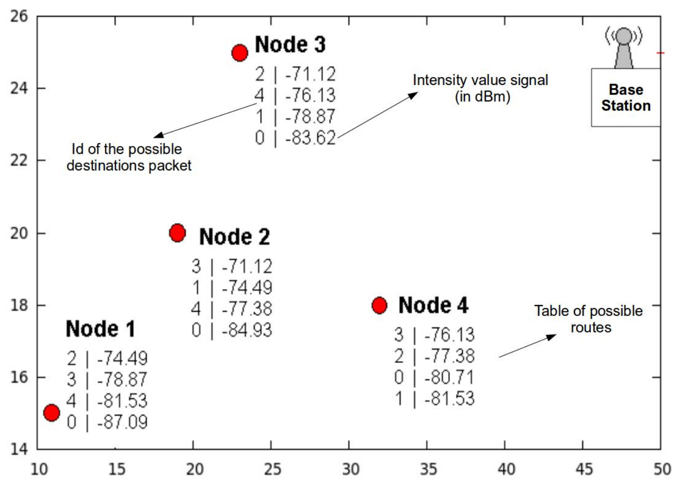

Figure. 2. Creation of each node initial tables.

Despite this initial table indicates the nearest cluster-head node to pass the packet, it contains wrong routes. For example, node 2 has as first route the node 3, but this node has node 2 as well as the first route, causing a loop in the network. Another wrong fact is that, node 2 has node 1 as route option, but it is not a good alternative because the packet is transferred in an opposite direction to the Base Station.

To solve these problems, phase 2 of the algorithm is performed. Each cluster-head sends their initial table to the base station so that it can check and correct them.

When the base station obtains all tables from all cluster-head, it performs an algorithm to determine whether a cluster-head can be in another cluster-head′s route table. The algorithm can be seen below:

$$IF \; \{ \; I - noX - EB < I - noY - EB \; \} \; THEN$$

"The Y node is a possible route to the X node"

where:

$I - noX - EB$ = Intensity of a packet that the node X received from base Station

$I - noX - EB$ = Intensity of a packet that the node Y received from base Station

If the node Y received a packet of the base station with an higher RSSI than node X, it means node Y is closer to the base station than node X. The figures below show the performance of this algorithm to correct the tables assembled in Phase 1.

As seen in Fig. 3, the Base Station corrects the initial routing table of the node 2. It checks whether the node 3 may be a possible route to node 2. Since the test is satisfied, the node 3 remains in the table.

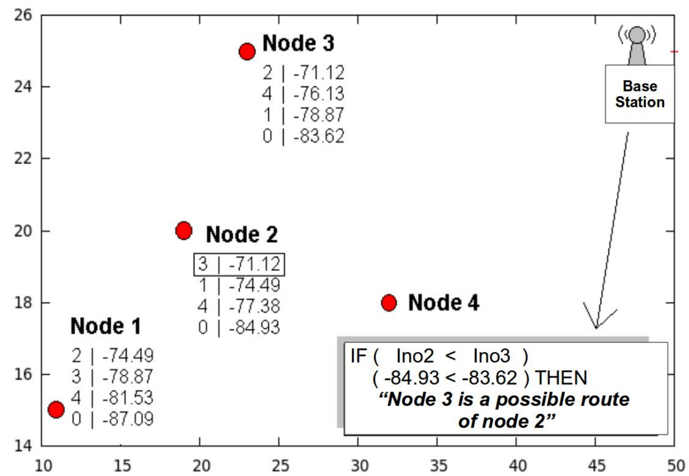

Figure. 3. Checking if node 3 can be a route to node 2.

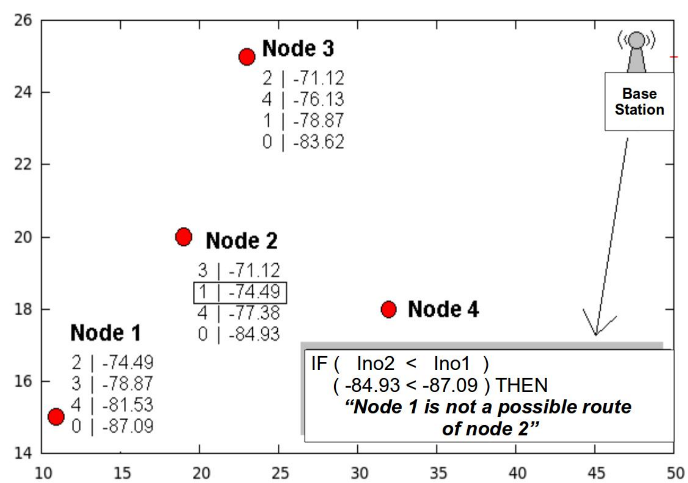

Figure. 4. Checking if node 1 can be a route to node 2.

The test done in node 1 is not satisfied, then it will not be part of the routing table of node 2. The procedure can be seen in Fig. 4.

Node 4 is approved and remains as a route of node 2 as shown in Fig. 5. The Base Station indicated by Id (identifier) zero in the table always remains; it is one last option route of

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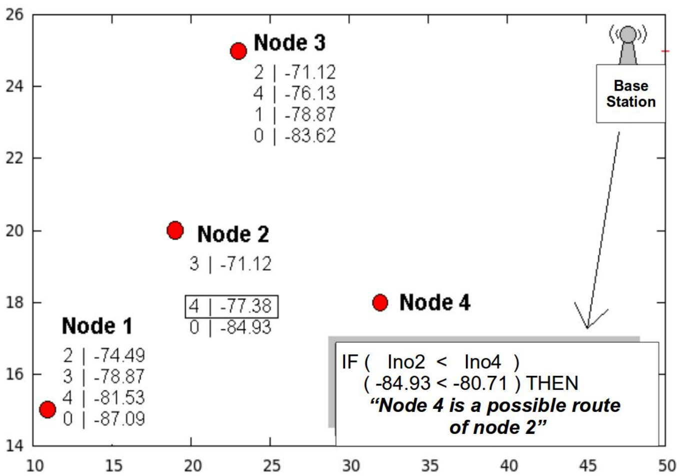

Figure. 5. Checking if node 4 can be a route to node 2.

the node. The reason is, if it is not possible to send data to any node in the network, it sends it to the base station.

After reviewing the table of each cluster-head, the base station sends back to the nodes the correct tables, free of loops and wrong forwards that aren't in its direction. Fig. 6 shows the final result table of each node after the checking performed by the base station.

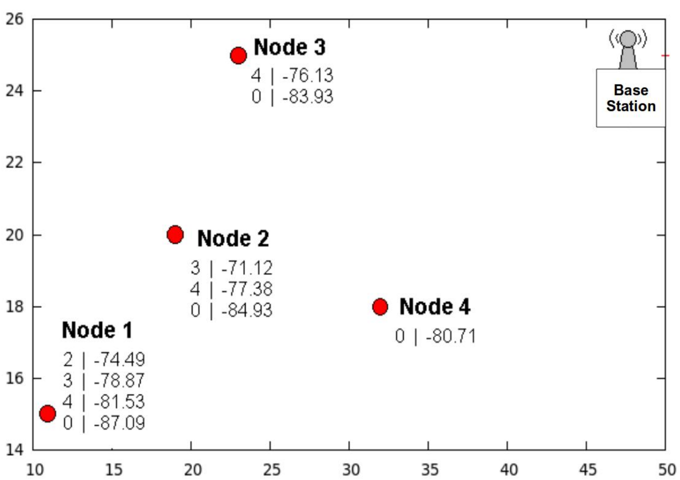

Figure. 6. Final result of route tables.

Thus, the process of calculating routes ends, where each leader node will not transmit directly to the base station, but for some other closer cluster-head to it indicated in its routing table. After that, the collection and transfer of data is started.

IV. Results

We evaluated the performance and validity of the proposed algorithm through simulations. The proposal was incorporated into the LEACH protocol making it multi-hop. We compared the obtained results of this approach to the results of the original version of LEACH using Castalia simulator [14]. This simulator is designed specifically for sensor networks being an extended module of OMNET++ simulator. Castalia has realistic wireless modeling channel and radio modules, where nodes behave very close to reality in the use of the radio.

The metrics used in the simulation were:

- ***Average consumption per node.*** In this metric, it is evaluated if the algorithm provided energy savings to the sensor nodes.
- ***Sending cost per energy consumed.*** This metric represents the total number of packets transmitted by the average consumption of each node. It indicates that the network took it best energy capacity due to the multi-hop calculation. It also indicates that the network has consumed less energy and sent a greater amount of packets.
- ***Time of death of the first node.*** This metric checks the network coverage time, i.e., the time that the network works 100% in data collection. Since a node dies, that coverage is no longer full.
- ***Time of Death 80% of nodes.*** With this metric, it is possible to check how long the network survived. Thus, we can notice whether the proposed idea has extended the network life.

The scenarios used in the simulation and evaluation of results are defined in Table 1. The energy of each node was set to 5 joules. The simulation time was 60 seconds. This period of time was set because at the end of that value most of nodes are almost inactive since the initial energy is low. The nodes were randomly distributed in the created area. The time for each round of the LEACH protocol was 20s. The number of cluster-head in every round was 5. Each simulation was run 33 times defining a confidence interval of 95% for all results.

TABLE I
Scenarios used in simulations

Scenario	Number of nodes	Area (m x m)	Base Station Position
1	50	50 X 50	(25, 100)
2	100	70 X 70	(35, 140)

Figures 7 and 8 show the results related to the average energy consumption of the nodes in the two scenarios, respectively.

It is possible to see in the first scenario that in the MH-LEACH protocol has better average power consumption when compared to LEACH. The values of the average consumption were 1.82097 and 1.63964 for LEACH and MH-LEACH respectively. The gain of the proposed approach was approximately 9%.

In the second scenario, the MH-LEACH protocol also obtained better values compared to the original LEACH. The results for the average consumption were 1.69509 and 1.59406 for LEACH and MH-LEACH respectively. The gain was approximately 6%.

Figures 9 and 10 show the results for the total number of packets transmitted by the average energy consumed. The higher that value, the better the protocol performance, since it was possible to send more packets with a low consumption.

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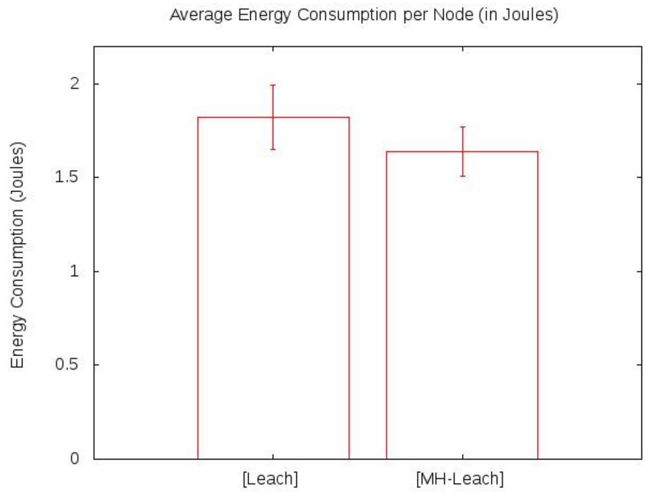

Figure. 7. Average energy consumption per node Scenario 1.

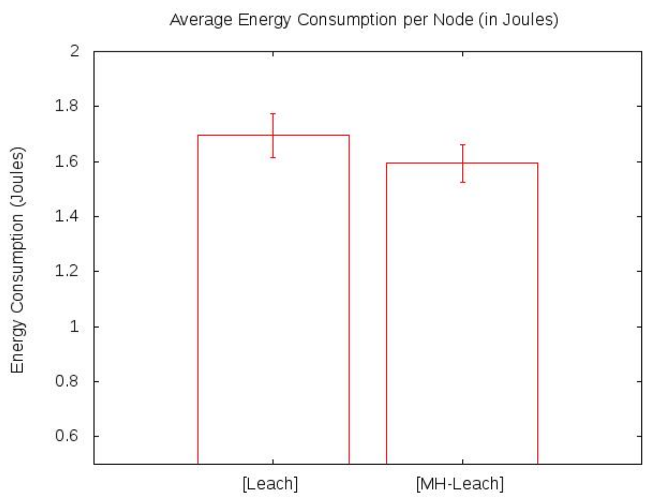

Figure. 8. Average energy consumption per node Scenario 2

In scenario 1, the LEACH and MH-LEACH obtained the following results, 99.765 and 129.723 respectively.

In scenario 2, the results were 236.798 and 266.671 for LEACH and MH-LEACH respectively. As can be seen, the LEACH protocol using the new algorithm achieved a better rate in both scenarios, i.e., more packets are sent with an energy efficient consumption.

Figures 11 and 12 show the results for the metric related for the first time that the network node dies. In scenario 1, the times of death were 22.4115 and 23.4351 for LEACH and MH-LEACH respectively. The results show that the proposed approach had a greater coverage time.

In scenario 2, the results showed the following values, 22.1991 and 23.2233 for LEACH and MH-LEACH respectively. In this scenario, the LEACH protocol with the proposed algorithm once again obtained better results than the original version of the protocol.

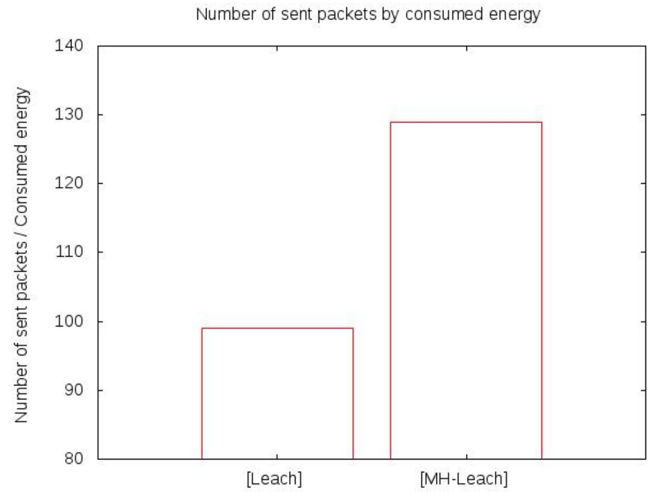

Figure. 9. Number of sent packets by consumed energy Scenario 1

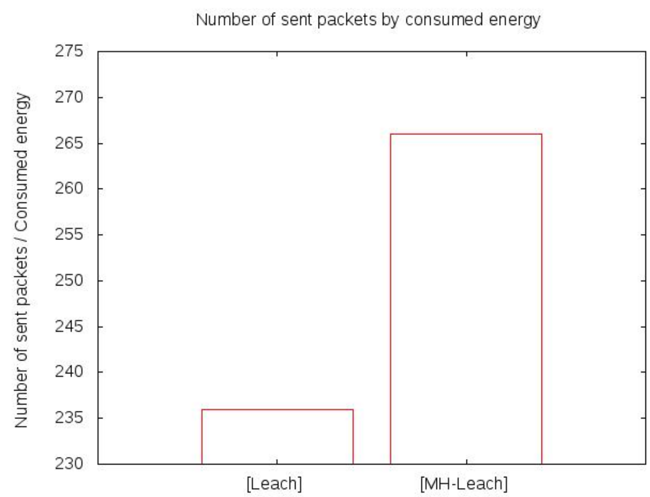

Figure. 10. Number of sent packets by consumed energy Scenario 2

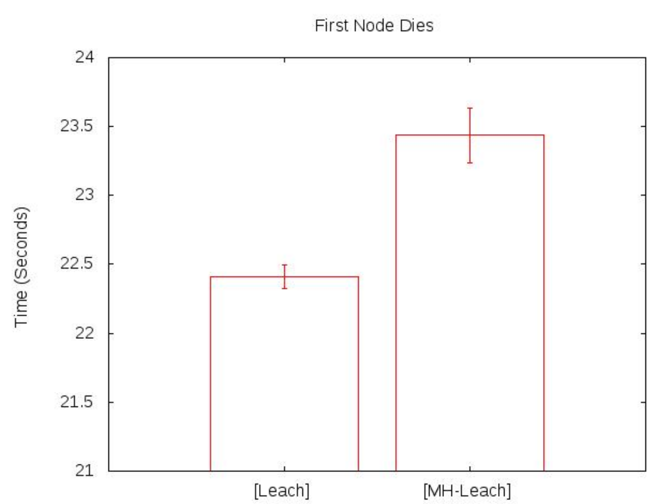

Figure. 11. Time of first node death Scenario 1

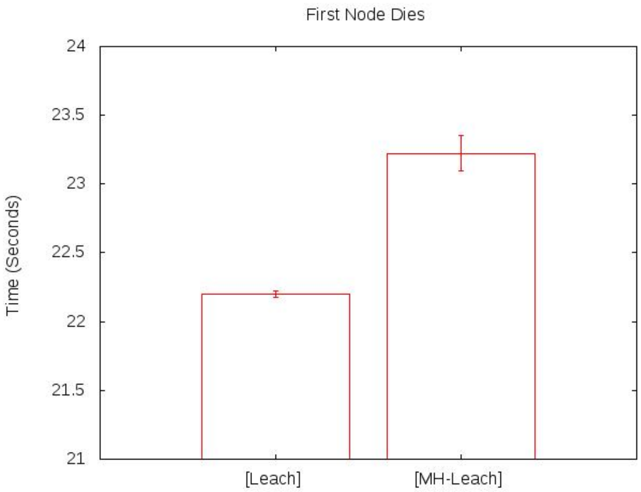

Figure. 12. Time of first node death Scenario 2

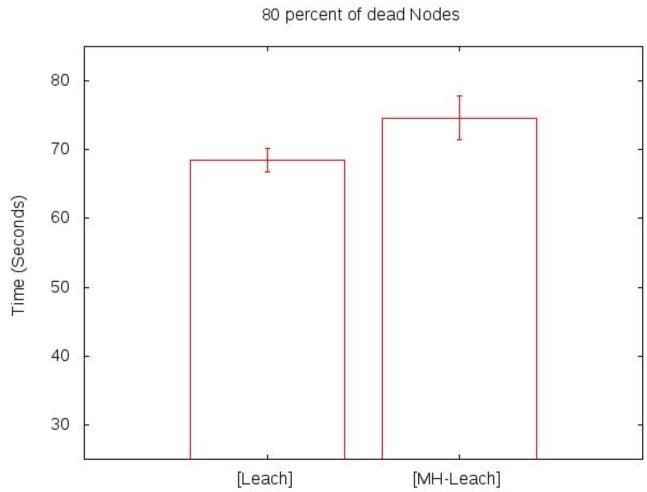

Figure. 14. Time for 80 percent of dead nodes Scenario 2

Figures 13 and 14 show the results for the metric that shows the time of death of 80% of nodes. There is a small detail concerning the calculation in this metric. The simulation time was increased to 120s generating a new simulation. This extension was done to ensure the collection of the times of death of at least 80% of nodes.

The times results obtained in scenario 1 were 54.1589 and 64.1114 for LEACH and MH-LEACH respectively. The new algorithm has obtained a longer time indicating that the network survived longer, i.e., since the nodes saved more energy transmitting to closer nodes, the network lifetime was extended.

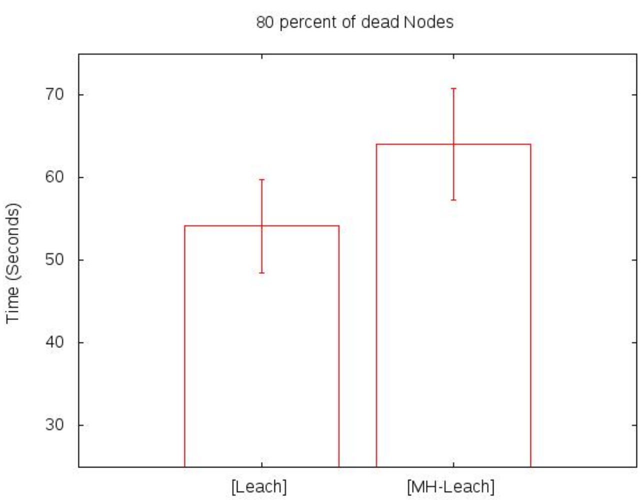

Figure. 13. Time for 80 percent of dead nodes Scenario 1

In scenario 2, concerning this metric, the following values were found: 68.4805 and for LEACH and 74.6026 for MH-LEACH. It is observed that the proposed idea got better results when compared to other protocol.

V. Conclusion and Future Work

The purpose of the study was to develop an algorithm for establishing multi-hop communication between sensor nodes in a network, with the main goal of saving energy. To achieve this purpose, we used the feature that greater signal intensities indicate node proximity. The base station was also used in order to perform a centered calculation to avoid errors on the use of found routes.

From the experiments, it was observed that the new algorithm achieved improvements when compared to the LEACH protocol. The gains were observed in power consumption and network lifetime, which was extended.

We conclude that the proposal is presented as an interesting idea that saves energy in sensor networks, which can be adapted to other single-hop protocols to achieve improvements in their running.

For future works, the proposal will be to adapt this technique in others protocols, like LEACH-C and ALEACH. Another future activity, it will be the development of a mechanism for the cluster-head node to use other possible routes of its table within a round taking into account the battery remains in the neighboring leaders.

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