BEE-C: A Bio-inspired Energy Efficient Cluster-based Algorithm for Data Continuous Dissemination in Wireless Sensor Networks

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***Abstract*—Wireless Sensor Network is a special type of ad hoc networks that show many challenges, mainly related to energy consumption of sensor nodes. This paper presents the BEE-C, a hierarchical routing algorithm bioinspired by the behavior of bees for Wireless Sensor Networks (WSN), which aims to save energy of sensor nodes. The BEE-C is based on the LEACH (Low Energy Adaptive Clustering Hierarchy) protocol and LEACH-C (LEACH Centered) protocol, which are two well known protocols for WSN in the literature. The BEE-C is applied to sensor networks with continuous data dissemination. The results show gains on BEE-C compared to LEACH and LEACH-C.**

I. Introduction

The Wireless Sensor Networks (WSNs) are a unique set of ad hoc networks that allow monitoring of the physical world through networks of small sensors densely or sparsely distributed. These networks are formed by hundreds or thousands of multifunctional sensor nodes with low energy charge, operating autonomously in an environment, with limited computational capabilities and a base station, which are responsible for receiving data from surrounding sensor nodes.

Today, WSNs are targets of many challenges. One of them is related to the scarcity of available energy at sensors, and a large part of the research done currently, look for efficient ways to emphasize saving energy of sensors, making these networks to live longer.

According to Ruiz [11],sensor networks can be classified into two categories, concerning the data flow: event driven network and networks with continuous data dissemination. In the event driven networks, data is sent to the base station only when an event raised. In networks with continuous data dissemination, data are constantly sent to the base station. The network lifetime is very important for such networks, because the longer the networks last, the more data will be sent.

A widely used technique to increase the efficiency of network energy and thereby to increase its lifetime is network clustering. A clustered network is a divided network into groups of nodes, with a leader in each group, which is responsible for receiving the data from the group, making the aggregation and sending the data back to the base station.

Despite the opportunities that the use of clustering in sensor networks bring along with, the problem of NP-hard is still remained, i.e., it is not resolvable in polynomial time by a deterministic algorithm [6]. Thus, the techniques which find good solutions in a short time is essential, especially in sensor networks since it is very critical if the messages transmissions are delayed long. There are many clustering algorithms [1], however, bio-inspired algorithms have achieved the best results for clustering data [7], [2], [10].

Bioinspired algorithms try to solve different problems by mathematical modeling of natural intelligent behaviors. Many of them are abstract biological behaviors with coordinated management patterns, such as an ant colony, shoal, hive bees, wasps, termites, bacteria and a group of birds flocking together.

The proposed algorithm, BEE-C, was developed based on the LEACH-C protocol [4]. however differently from LEACH-C, BEE-C uses an algorithm based on the bioinspired behavior of bees to achieve the clustering process more efficiently.

BEE-C has been developed for networks with continuous data dissemination. It is essential that a good power management is performed, so that the WSN has a longer lifetime. In order to make the power management more efficient, an objective function that uses the model of consumption of energy network with some other key parameters such as WSN lifetime, transmitted data, extended radius area of network coverage and reduced energy consumption are presented in this research.

The evaluation results of BEE-C, compared with the LEACH and LEACH-C protocols show significant gains.

This paper has discussed the following sections: Section 2 presents the related works, Section 3 presents the proposed algorithm,, the BEE-C; Section 4 outlines the results and finally, the conclusions and future works are presented in section 5.

II. Related Works

This section presents the LEACH [5] and LEACH-C [4], which are the basis for BEE-C development and performance evaluation. Moreover, other bioinspired routing algorithms which use clustering in WSN including PSO-C [8], T-ANT [12] and GA-ABC [9] are presented.

A. LEACH

The Low-Energy Adaptive Clustering Hierarchy protocol (LEACH) [5] is a hierarchical protocol that optimizes energy consumption in order to increase the network lifetime. In LEACH, nodes organize themselves into clusters, with a node as a leader (cluster-head). All non-leader nodes transmit their data to the cluster-head, while the cluster-head receives data from all cluster members, performing data processing functions (eg, data aggregation), and transmits data to the base station.

The LEACH works by rounds. In each round, the leaders are changed in order to distribute the power consumption in the network. Two phases make the rounds: the forming clusters, and the communication phase. In the forming clusters phase, the choice of leaders is made by a distributed algorithm and the source nodes choose to join the nearest cluster-head. In the communication phase, data is transferred to the base station, including aggregation / data fusion by the leaders.

B. LEACH-C

The LEACH-C [4] is derived from LEACH in that it uses a centralized algorithm for forming 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 in all network nodes, the base station calculates the average energy of the nodes in each round. The only nodes which might be cluster-heads are the ones which show the energy level above average, and according to these nodes, the base station runs the Simulated Annealing algorithm to determine the best cluster-heads. After finding the clusters and the corresponding leaders, the base station transmits the information to the network nodes. Then, the nodes transmit the data to the leaders of the groups, which send the data to the base station.

C. PSO-C

The Particle Swarm Optimization - Centralized (PSO-C) [8] is a bio-inspired protocol based on LEACH-C which uses particle swarm optimization. The two phases of the PSO run similar to LEACH-C, the difference is in the use of the bioinspired algorithm by PSO-C. In its way of finding the cluster-heads, which is minimizing the intra-cluster distance between the cluster nodes and their cluster-heads, thus, optimizing the power management on the network.

D. T-ANT

In 2006, [12] the T-ANT was introduced as a distributed routing protocol bioinspired in the behavior of an ant colony that takes two phases to the clustering process: the cluster formation phase and communication phase. The T-ANT uses two methods: estimation of variance and clustering methods. To form clusters, an ant cluster-head election is held. The base station implements a series of ants (control messages) in order to determine the cluster-heads through the principles of alignment and separation found in the biological systems. The main objective of T-ANT is to optimize the network lifetime, by forming clusters, uniformly distributed, at a minimal cost of energy consumption.

E. GA-ABC

The GA-ABC [9] is a bio-inspired algorithm that uses Genetic Algorithms (GA) and Artificial Bees Colony (ABC) for the formation of clusters in a WSN. The protocol is divided into two stages: the setup phase and data aggregation. In the setup phase the algorithm uses Genetic Algorithms to find the best cluster-heads, and uses ABC to define the nodes that participate in each cluster. After this phase, the base station sends all the network details to the nodes. At the stage of data aggregation, the nodes send data to their cluster-heads which in their turn send to the nearest cluster-head or base station.

III. BEE-C Protocol

This paper proposes BEE-C based on LEACH-C algorithm, which uses an bioinspired algorithm in bees behavior based on the Honey Bee Mating Optimization (HBMO) [2] to perform the clustering of network nodes. Besides the use of a bio-inspired algorithm, BEE-C implements new objective functions that aim to optimize energy consumption. Since it is applied to networks with continuous data dissemination, the main objective of BEE-C is to extend the network lifetime.

For the proposed algorithm the following assumptions are considered:

- The base station is fixed and stays away from the nodes;
- The nodes are all equipped with control features that can vary their transmission power;
- All the sensor nodes are static;
- The sensor nodes know their location.

In the following subsections we will present: the model of the network energy consumption, which is from paramount importance to development of objective functions; the operation of the proposed algorithm and then the used objective functions.

A. Energy Consumption Model

According to Heinzelman [4], the energy dissipation in a sensor node is performed according to the model shown in Equations 1 and 3.

The energy consumption for transmitting a message of k bits at a distance d is:

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

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

and to receive the message, the radio spends the E_{Rx} energy:

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

where:

$E_{Tx-elec}$ = Spent energy in transmission;
$E_{Rx-elec}$ = Spent energy 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} = Spent energy per bit transmitted or received

B. BEE-C Operation

The proposed protocol works in rounds, the time of each round is defined as a parameter of the protocol. Each round is composed of two phases: clusters formation and data communication.

In the first phase, the formation is made in groups. The process of formation of clusters is held centrally. The start of this process is carried out similarly to LEACH-C, where each node sends its geographical position and its amount of energy to the base station. According to the data, the base station calculates the average consumed energy. Only the nodes that have their energy level over the average are eligible.

To find the best clusters, the base station performs a bio-inspired algorithm in bees, to minimize or maximize (depending on the function) the objective function of the algorithm. To this proposal, each network node is considered as a Cartesian Point. The nodes are grouped by their minimum distance, and the centroids are the leaders of the groups. Each bee of the algorithm is represented by a set of possible network leaders. After running the bioinspired algorithm, the clusters are formed from the solution phase and then starts the data transmission as the LEACH works.

1) Bioinspired algorithm used in the Formation of Clusters: The algorithm used in the formation of clusters is based on HBMO [2], which is an algorithm that is based on the behavior of reproduction of bees. For this algorithm, three types of bees are considered: the drone, the queen and the workers. Each of these types has different functions. The queen bee is only responsible for reproduction of new bees, the drone has the sole function of mating with the Queen, however, the workers are responsible for cleaning the hive, searching for food, feed the queen and the drones, and other tasks.

In BEE-C, the queen bees (solutions) and the drones are represented by a set of possible cluster-heads for the network.

In order to form the clusters, the algorithm performs the following steps:

1) It starts a population of solutions, ie, from the eligible nodes a set of solutions is formed ;
2) It chooses the best solution as the queen bee, this choice is made by calculating the objective function, which determines the quality of a solution;
3) It defines the other solutions as drones;
4) It starts the iterations of the algorithm to satisfy a stopping criterion, in BEE-C this criterion is the number of generations;
   a) It performs the natural selection of drones that will mate with the queen bee. The better the drone, the more chance it has of being selected. The BEE-C uses the method roulette selection;
   b) It performs the process of mating with the queen and the drone to generate descendants. In order to achieve this objective, the BEE-C uses the method for crossing binary mask;
   c) It applies a local search in the descendants through mutation (replacing a cluster-head of the solution by another eligible node);
   d) If the best descendant is better than the queen, the replacement is performed.

2) First Objective Function: The first choice of objective function for this work is based on the model of energy consumption of the network. This function tries to predict the sum of the average amount of energy of each node in the clusters that the network will have after the rounds. Thus, the algorithm has to maximize this function.

Initially the amount of energy E_1 that the cluster-cluster head will spend k to send the packets to the base station is calculated by using Equation 4:

$$E_1 = N_k \cdot (E_{elec} + \epsilon_{tr} \cdot d^4_{CH-to-BS}) \quad (4)$$

where N_K is the number of nodes in the cluster k, E_{elec} is the spent energy per transmitted or received bit, ϵ_{tr} is the parameter to the energy consumption model of two radius, used for large distances between the source and the target and $d_{CH-to-BS}$ is the distance from the cluster-head to the base station.

E_2 is the amount of energy that the source nodes will spend to send data to the cluster-heads by using Equation 5:

$$E_2 = (\sum_{j=1}^{N_k} E_{elec} + \epsilon_{fs} \cdot d^2_{no_j-to-CH}) \quad (5)$$

where ϵ_{fs} is the parameter for the consumption model in free space, used when the distance between the source and target is short, $d_{no_j-to-CH}$ is the distance from the node j to the cluster-head.

In Equation 6, the consumed energy E_3 by cluster-heads for data fusion is calculated by:

$$E_3 = N_k \cdot E_{BF} \quad (6)$$

where E_{BF} is the consumed energy per bit for data fusion.

Finally, in Equation 7, the energy consumed by cluster-heads E_4 to receive the data from source nodes is calculated by:

$$E_4 = (N_k - 1) \cdot E_{elec} \quad (7)$$

The total spent energy E_{C_k} by the k cluster is:

$$E_{C_k} = E_1 + E_2 + E_3 + E_4 \quad (8)$$

The total energy E_{T_k} of the cluster k is:

$$E_{T_k} = \sum_{j=1}^{N_k} E_{no_j} \quad (9)$$

Thus the function F is calculated by obtaining the sum of the averages of the remaining energy of the nodes in each cluster:

$$F = \sum_{k=1}^{p} \frac{E_{T_k} - E_{C_k}}{N_k} \quad (10)$$

where p is the number of clusters in the network.

3) Second Objective Function: For this second option of the algorithm, the objective function of LEACH-C was used as the subfunction, and two other subfunctions were added. The first subfunction is:

$$f_1 = \sum_{i=1}^{N} \min_{k \in K} d^2(i,k) \quad (11)$$

where N is the set of network nodes, K is the set of cluster-heads and d is the distance. This function looks for the least cost for the network source nodes, reducing distances to their cluster-heads. The second sub-function is:

$$f_2 = \sum_{i=1}^{N} E(n_i) / \sum_{k=1}^{K} E(CH_k) \quad (12)$$

where $E(n_i)$ is the energy of the node i and $E(CH_k)$ is the energy of the cluster-head k. Minimizing this function, the set of cluster-heads with more energy are found. The third sub-function is:

$$f_3 = \sum_{k=1}^{K} d(CH_k - to - BS) \quad (13)$$

where $d(CH_k - to - BS)$ is the distance from the cluster-head k to the base station. The minimization of this function finds the cluster-heads with the shortest distance to the base station, which aims to lower energy consumption when transmitting data.

The balance in the three functions aims to find clusters where source nodes are close to the cluster-heads (f_1), the cluster-heads have excess energy (f_2) and spend very little power when transmitting f_3.

The objective function is calculated by multiplying the three subfunctions:

$$F = f_1 \times f_2 \times f_3. \quad (14)$$

This multiplication is performed because we considered the three subfunctions with the same weight.

IV. Simulations and Results

In order to evaluate the performance of our proposed algorithm, it is simulated and tested. Two algorithms of BEE-C are considered in the comparisons: the BEE-C1 which uses the objective function 1, and BEE-C2 which uses the objective function 2.

A. Environment Used for Simulation

For the simulations, the NS (Network Simulator) version 2.1b5 was used. Four scenarios were set to compare the different algorithms. The scenarios varied in the number of sensor nodes, network area size and base station positioning.

The table I shows the scenarios used in the simulations:

Table I
Scenarios used in simulations

Scenario	Number of nodes	Area (m x m)	Base Station Position
1	100	100 X 100	(50, 175)
2	200	100 X 100	(50, 175)
3	100	200 X 200	(100, 275)
4	200	200 X 200	(100, 275)

In the simulations, the radios can control their transmission powers in order to consume very little power to reach its destination as quick as possible. Nodes can be disconnected if they are not in use to save energy. Each node in the network has 1 Joule of energy and the size of sent packets is 500 bytes. The optimum amount of network clusters is 5% and the time of each round is 10 seconds [5]. The simulation ends when less than 5% of the network nodes are active. The type of the consumed energy and the energy parameters are the same as Heinzelmans used [5].

B. Results

This section analyzes the simulation results and compares the results which are obtained by BEE-C to results obtained by LEACH and LEACH-C.

The metrics in the simulations were: the amount of data sent to the base station, the network lifetime, full network coverage time (until the death of the first node) and consumed energy by the network. The scenario 1 of the table I is the default scenario, which was the same scenario used to show the results of the protocols of LEACH and LEACH-C [3].An interval of 95% was considered for all the results.

1) Amount of nodes sent to the base station: Figure 1 shows the average number of sent packets by the protocols in each scenario. It is possible to observe that in all scenarios, the number of packets sent by BEE-C1 was higher than the others, and the BEE-C2 could also send more packets than the LEACH and LEACH-C. The average gain of BEE-C1 in sending packages comparing to LEACH was approximately 5%, and BEE-C2 achieved an average gain of 1% over LEACH-C.

In scenario 1, the BEE-C1 had the greatest gain in relation to LEACH-C which was about 6%, meanwhile the BEE-C2 had a gain of little more than 1%. However, it can be seen that when the density of the network increases (Scenario 2), the gain of BEE-C1 decreases to 1.5% and BEE-C2 gain was only 0.5% over LEACH-C. The protocol LEACH in scenarios 2 and 4, where the network has 200 nodes, had a big reduction in data transmission. This happens because LEACH form clusters in a distributed way, through the exchange of messages among the nodes and by increasing the number of nodes. Therefore, the number of collisions increases and the efficiency in the formation of groups decreases.

We can observe that the centralized approaches have a low variation in the results, so that for the same scenario, protocols performed several times will achieve similar results as long as the formation of clusters considers the nodes positions and its energy. Thus the choices of clusters may be similar, bringing greater confidence in simulation results. In LEACH, the variation coefficient of the data transmission is high, since the formation of groups is almost random, it may be effective in some cases but not in others.

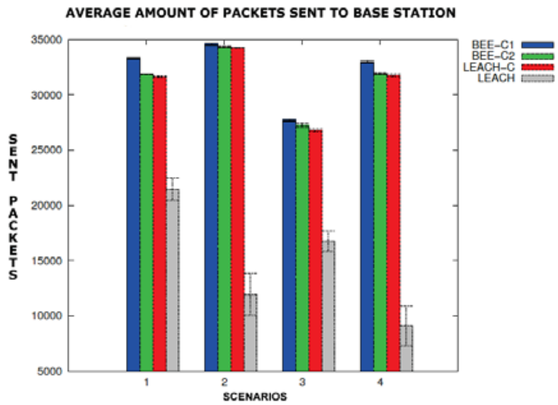


Figure 1. Average amount of sent data to the base station in each scenario

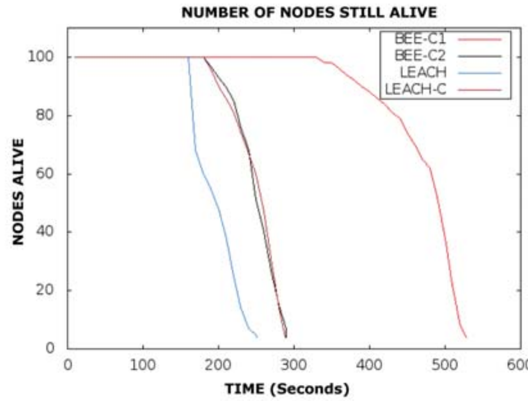


Figure 3. Number of alive nodes according to time

2) Total network lifetime: Figure 2 shows the average network lifetime. This time is important, since the greater the network lifetime requires a greater time to monitor the environment. The average gain in BEE-C1 lifetime comparing to LEACH-C was 55%, when was compared to LEACH, the gain was over 100%. The average BEE-C2 lifetime was greater than LEACH-C in about 1%. It can be seen that in scenario 1, the lifetime BEE-C1 gain is about 80% comparing to LEACH-C. In scenario 3, the gain is only 15%. Scenario 3 has the least density, ie, the nodes are sent into a very large area and away from the base station causing the network power consumption to increase. Although the algorithm forms clusters efficiently, the lifetime decreases. In all scenarios, the results of BEE-C2 were similar to LEACH-C results. The protocol LEACH had the worst lifetime in all scenarios, especially in scenarios 2 and 4, where the network had the largest number of nodes.

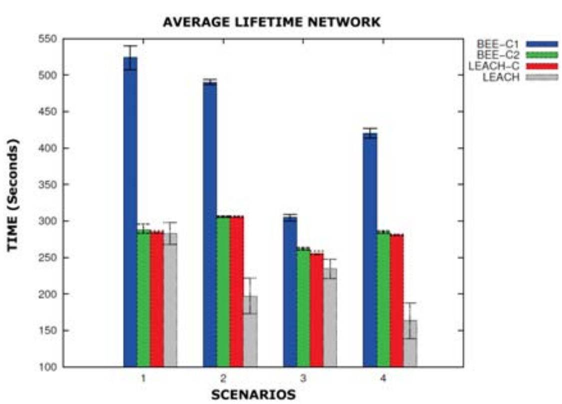


Figure 2. Average network lifetime in the different scenarios

Figure 3 shows the number of living nodes by time, considering the scenario 1. We can see that the sensor nodes in BEE-C1 are active for a longer period of time, followed by BEE-C2, which has the second best performance in this regard. Among the compared protocols, the LEACH sends the least data to the base station, but nevertheless it may have a good lifetime which is similar to the time of LEACH-C and BEE-C2.

3) Total network coverage time: Figure 4 shows the average coverage of the network, this value is calculated by obtaining the network lifetime to the first node death, i.e., when a part of the network area is not covered anymore. Concerning this aspect, the BEE-C1 was superior to LEACH-C approximately by 35% and more than 100% to LEACH, while BEE-C2 had a total average of network coverage about 10% more than the LEACH-C and about 50% more than the LEACH. It is important to note that in scenarios 3 and 4, since the nodes are dispersed over larger areas, the death of the first node occurs in the first few rounds in all compared protocols.

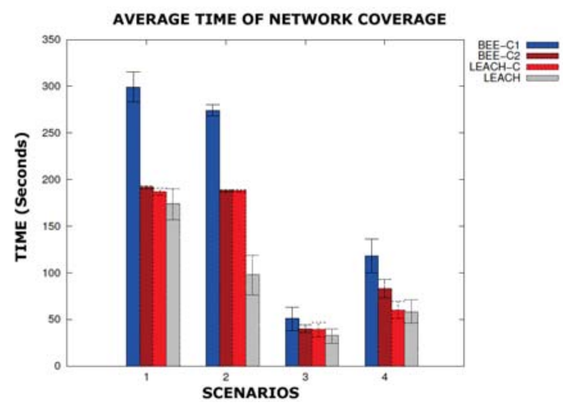
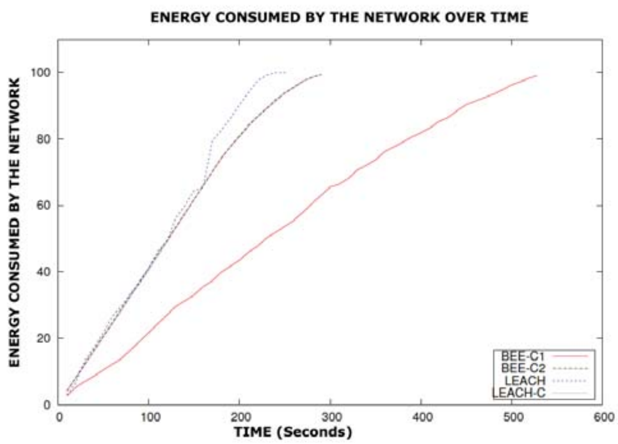


Figure 4. Average total network coverage time

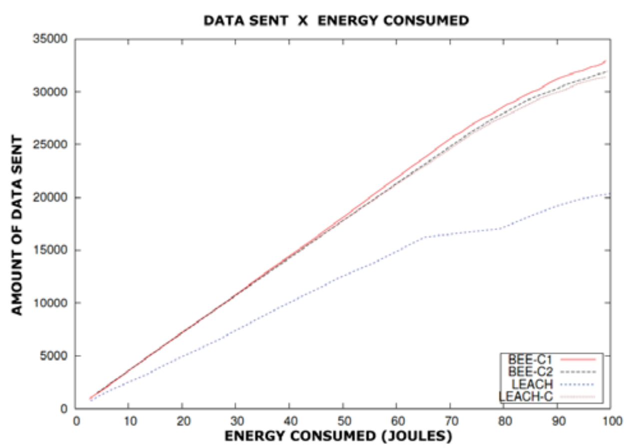
We can see in Figure 4 that the coefficient of variation of LEACH is very high, for instance the reliability of the average is lower in LEACH. The BEE-C1 and BEE-C2 protocols show the best results, and the BEE-C2 is the one with the most reliable results, since it presents the coefficient of variation less than other protocols. This result is the objective function of BEE-C2, which considers not only the amount of energy in the nodes, but also the distance to the base station, in the choice of cluster-heads.

Figure 3 it is noticed that the BEE-C1 time of coverage is greater than the lifetime of other compared algorithms. Furthermore, we notice that the time for total network coverage of BEE-C2 is almost equal to LEACH-C, which are higher than the covering time of LEACH.

4) Energy consumption: In all the simulations, virtually all the energy from the network is consumed in the network. Figure 5(a) shows a graph of the algorithms energy consumption of algorithms, considering scenario 1. We can observe from Figure 5(a) that the algorithms of LEACH-C and BEE-C2 show similar behaviors concerning energy consumption, while BEE-C2 may keep the network active for a slightly larger period. The BEE-C1 consumes less energy per time than the others. LEACH is unstable, it sometimes consumes little energy and sometimes it accelerates power consumption, thus it has a shorter lifetime if it is compared to the others.



(a) Amount of energy consumed (Joules) in the network over the time



(b) Number of sent packets by the consumed energy (Joules)

Figure 5. Network energy consumption

Figure 5(b) presents the graph of the data delivery according to the energy consumption, we see that the BEE-C1 can send a larger amount of data by the consumed energy, followed by BEE-C2, which has a small gain when compared to LEACH-C. Finally, the LEACH protocol has the lowest sending rate by the consumed energy.

V. Conclusion and Future Work

The main purpose of this research was development of a routing algorithm, BEE-C, to save energy in wireless sensors networks.

Among the studied protocols which used clustering, the LEACH and LEACH-C were noted and the latter was used as the basis for this purpose. For clustering the network, this study used a bioinspired clustering method in reproduction behavior of bees to group the sensor nodes in order to optimize energy consumption. In addition, two objective functions were developed, that aim to increase the lifetime of network by the reducing the energy consumption. The first objective function was developed based on the energy dissipation model and the second one was constructed by using the LEACH-C function, and improvements regarding energy consumption were added by cluster-heads.

The experiments showed that the algorithm had gains with the two functions, in regards to the number of sent packets to the base station, in the network lifetime, and in the total network coverage time, as a result of using the energy efficiently in the network.

In conclusion, we have two main future research goals that can bring about significant improvements to bioinspired algorithms. The first is either simplifying the first objective function, optimize the second objective function and normalize them. The combined function can enhance BEE-C functionality. The second goal is to use multihop communication between the cluster-heads to significantly reduce the power consumption of nodes thereby it makes even more efficient BEE-C. We will implement and validate other bioinspired algorithms, in order to compare them with BEE-C.

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