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Performance evaluation of hierarchical clustering protocols with fuzzy C-means

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ABSTRACT

The longevity of the network and the lack of resources are the main problems within the WSN. Minimizing energy dissipation and optimizing the lifespan of the WSN network are real challenges in the design of WSN routing protocols. Load balanced clustering increases the reliability of the system and enhances coordination between different nodes within the network. WSN is one of the main technologies dedicated to the detection, sensing, and monitoring of physical phenomena of the environment. For illustration, detection, and measurement of vibration, pressure, temperature, and sound. The WSN can be integrated into many domains, like street parking systems, smart roads, and industrial. This paper examines the efficiency of our two proposed clustering algorithms: Fuzzy C-means based hierarchical routing approach for homogeneous WSN (F-LEACH) and fuzzy distributed energy efficient clustering algorithm (F-DEEC) through a detailed comparison of WSN performance parameters such as the instability and stability duration, lifetime of the network, number of cluster heads per round and the number of alive nodes. The fuzzy C-means based on hierarchical routing approach is based on fuzzy C-means and low-energy adaptive clustering hierarchy (LEACH) protocol. The fuzzy distributed energy efficient clustering algorithm is based on fuzzy C-means and design of a distributed energy efficient clustering (DEEC) protocol. The technical capability of each protocol is measured according to the studied parameters.

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1. INTRODUCTION

WSN is one of the main technologies devoted to the identification, sensing, and controlling of physical environmental phenomena in real-time such as the detection and measurement of vibration, pressure, temperature and sound. [1-3]. The WSN can be incorporated in many sectors like street parking, smart roads, and industrial monitoring [4-5]. In general, WSN consists of several self-organized sensor nodes with limited energy, computational capacities, and bandwidth [6-8], which are deployed inarge quantitiesof sensorsin dedicated environments. Under hostile conditions, adjusting the node's battery under operating mode is impractical. An autonomous energy source (battery) supplies each sensor node and is fitted with a microcontroller, memory, and transceiver [2-7]. The base station (Sink), however, others data for processing and sends it to the central computer. A WSN managed by one or more base stations [1-4, 9].

In WSN the communication process requires a considerable quantity of energy. Energy consumptin optimization is one of the prominent problems facing wireless sensor networks. For this reason, improving the network's energy output is necessary in order to increase the system's lifetime [9]. To overcome this limitation a set of techniques have been developed to minimize the communication energy consumption [5]. Due to their energy efficiency, automated routing strategies such as single-hop,multi hop or clustering have been widely implemented at WSN [6].

Several researchers have proposed the routing algorithms to increase the lifetime of network. Based on the network layout, routing in WSN can typically be classified into flat routing, hierarchical routing, and location routing [10-12]. Among such protocols are the routing protocols for clustering. The network is partitioned into small areas in the clustering algorithm, and each part is controlled and regulated by the cluster head (CH). This is responsible for compressing the collected data and transmitting it to the base station through a single hop or multi-hop that can be linked to a powerful device over the internet or a satellite of the information sensed by the area nodes [12-16]. The clustering protocols saves resources to extend the network's lifespan [16]. That can also be a realistic attribute for large sensor networks, since the cluster heads are easier to handle than the whole network. Multiple clustering routing protocols using multi-paths have been proposed on the basis of load balancing according to the following order LEACH [16-19], DEEC [12, 15, 16]. The clustering protocols can be divided into two types: the clustering algorithm with homogeneous schemes in which all the sensor nodes have the same initial energy; and the heterogeneous clustering protocols in which all the sensor nodes are delivered with a different amount of power at network startup [18].

In this paper, we conduct an analysis of the performance parameters of some effective hierarchical routing protocols, the low-energy adaptive hierarchy protocol known as LEACH [6], the stable election protocol (SEP) [20], the distributed energy-efficient clustering protocol (DEEC) [12], and our porpositions: the F-LEACH protocol and the F-DEEC protocol. The rest of the paper is structured as follows: The relevant research and benchmarking are presented in section 2. Section 3 introduces introduces the F-LEACH protocol. Section 4 describes the F-DEEC protocol. Section 5 establishes models and the analysis of the results. Eventually, section 6 finalizes the paper based on the findings obtained and possible research

2. RELATED WORK AND BENCHMARKING

In the recent past, a number of clustering algorithms were proposed for WSNs, among these are proposed found towards effective data communication and data processing with optimal resource usage in the WSN. In this part, we describe some of the most effective routing algorithms of WSN. Researchers have conducted a variety of works focused on application and network layout to advance routing protocols in WSN. There are also several parameters to consider when designing the routing protocol. Energy performance is one of the most obvious variables directly impacting the lifespan of the network. In this paper, we provide some examples of the energy-efficient routing protocols.

2.1. Low-energy adaptive clustering hierarchy (LEACH)

The LEACH protocol [8, 18] is the first protocol that uses a pure probabilistic model to pick CHs and to rotate the CHs periodically to balance energy usage. The dynamic clustering mechanism has been introduced, where a node elects itself by unique probability to become a CH and transmits its status to all nodes [3, 21]. In certain instances, however, inefficient CHs are selectable. This is due to the fact that LEACH only relies on a probabilistic model. Some CHs may be very close to each other and maybe situated at the WSN's edge. Such inefficient heads of Clusters can have a negative impact on energy efficiency in the network. The LEACH cycle moves to circles. Every round has two phases: the first phase is set- up for organizing the clusters and selecting CHs; the second phase is stable-state for transmitting data to the base station. CHs elections are based on the desired percentage of CHs and the number of iterations a node has taken on CHs function [22, 23]. A node ***s*** is therefore a random value between 0 and 1. If the value is below the T(s) threshold, the node will become CH. The threshold is set as:

$$T(s) = \begin{Bmatrix} \frac{p}{1-p\left(r mod\left(\frac{1}{p}\right)\right)} & if s \in G \\ 0 & otherwise \end{Bmatrix} \tag{1}$$

where *p* is the target percentage of CH nodes within the sensor population and ***r*** is the current round number, where G is the set of nodes that were not CHs in the last *1/p* rounds [3, 12, 24]. With all the advantages of the LEACH protocol, by dispersing the cluster heads across the network, it suffers from the development of quality clusters. Therefore, the authors in [13, 19] proposed LEACH-C recommend a centralized approach to selecting CHs for an improved version of LEACH. In LEACH-C all nodes are sent to the base station with their id, energy level, and GPS coordinates. It is the base station's role to select a few nodes as CH based on their energy level. For the current round, nodes with energy, greater than average energy, are selected as CH. The major downside of this approach is that it dissipates the energy of all nodes in each round for the transmission of the information to BS.

2.2. Stable election protocol (SEP)

It makes LEACH interesting to experiment with the use of other probability-based models such as A stable election protocol (SEP) [20] as a method. The SEP protocol adopted the similar procedures adopted by the LEACH protocol for the selection of cluster heads. The choice process of cluster heads is based on the weighted probability of each node being a cluster head [7]. The SEP protocol takes into account the heterogeneities in each sensor node in the initial energy quantity. The SEP protocol categorizes the sensor nodes into two sets according to the initial energy: advanced nodes and regular nodes. Advanced nodes have initial energy that is very high than regular nodes, the additional energy factor between advanced and standard nodes is denoted by α. The advanced nodes are equipped with $(1+\alpha)$ more energy quantity than the regular nodes. The advanced nodes in SEP protocol have more probability of being cluster head than regular nodes. The SEP uses two weighted probabilities of election: One for regular nodes, and the other for advanced nodes [13]. Where P_{normal} is the weighted probability of election for normal nodes, and the P_{adv} is the weighted probability of election for the advanced nodes. Accordingly, the weighted probabilities of the usual node and advanced node are generated accordingly [12, 25].

$$P_{normal} = \frac{p}{1+m\alpha} \tag{2}$$

$$P_{adv} = \frac{p}{1+m\alpha} * (1+\alpha) \tag{3}$$

Where m is the proportion of advanced nodes with nodes with α times more energy than the normal nodes.

In SEP protocol, each node type has a threshold; $T(_{snormal})$ is the normal node threshold and $T_{(Sadv)}$ is the advanced node threshold. Consequently, the normal and advanced threshold for equation of nodes is:

- For normal nodes:

$$T(\mathrm{snormal}) = \begin{cases} \dfrac{P_{normal}}{1-P_{normal}\left(r \bmod \left(\frac{1}{P_{normal}}\right)\right)} & \text{if } s \in G' \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

where G' is a set of normal nodes which can become CH and m is the proportion of advanced nodes with α times more energy than the normal nodes [26].

- For advanced nodes:

$$T(\mathrm{sadv}) = \begin{cases} \dfrac{P_{adv}}{1-P_{adv}\left(r \bmod \left(\frac{1}{P_{adv}}\right)\right)} & \text{if } s \in G'' \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

where G'' is a set of advanced nodes that have not become cluster heads within the last $\frac{1}{P_{adv}}$ round.

2.3. The distributed energy efficient clustering protocol (DEEC)

The DEEC protocol is an energy-intensive, distributed clustering protocol for the heterogeneous wireless sensor network. Unlike the LEACH protocol and the SEP protocol, the DEEC protocol adopts an enhanced method for the collection of CHs used by the LEACH protocol and the SEP protocol, to measure the probability of the original and residual energy level of the nodes [8, 27]. The CHs are chosen by a probability on the basis of the ratio of each node's remaining energy to the average network energy. For each node, the round number of the revolving epoch is different depending on its original and residual energy. The DEEC protocol adapts each node's rotating epoch to its capacity. Nodes carrying high initial and remaining energy have greater chances of being CH than low-energy nodes [23, 28]. This method allows for prolonging the network lifetime of the DEEC protocol. But it is difficult to provide a global knowledge of the average energy of each node's network. According to (7), the DEEC protocol assumes an ideal value for the network lifetime used to measure the reference energy that each node will extend during each round. The DEEC has the drawback that the advanced nodes are still penalized when the residual energy is limited and when it is equal to regular nodes. The advanced nodes would die fast on these circumstances than the other nodes. The average probability of i[th] node to be a CH during the next round is given by pi.

$$pi = p\frac{E(r)}{E(r)_i} \tag{6}$$

Where p is the optimal propobilty and E(r) is the average energy round, set (7).

$$E(r) = E_{total}(1 - R)/N \tag{7}$$

Where R denotes the total rounds of the network lifetime.

The value of the total Energy is given (8).

$$E_{total} = N * (1 - m) * Eo + N * m * Eo * (1 + \alpha) \tag{8}$$

Where *R* denotes the total rounds of the network lifetime. Let E_{round} denote the energy consumed by the network in each round. *R* can be approximated (9).

$$R = \frac{E_{total}}{E_{round}} \tag{9}$$

2.4. Fuzzy C-means clustering algorithm

The fuzzy C-means clustering algorithm (FCM), which was developed by Dunn in 1974 and improved by Bezdek in 1987, has been extensively studied and applied [29, 30]. FCM is a clustering algorithm that is unsupervised as same as the k-means algorithm with the same cluster division purpose. Nonetheless, k-means is a hard set based algorithm, and FCM is an algorithm based on the non-crisps approach (all individuals are listed in two groups: 1 or 0) [30-32]. This algorithm works by assigning affiliation to each sensor node that corresponds to each cluster center. This process is based on the distance between the cluster center and the sensor node. Therefore, the closer the sensor node is to the cluster center, the stronger its membership in cluster center is [30-33]. The FCM algorithm represents an iterative optimization algorithm that minimizes the following objective function [33].

$$f = \sum_{i=1}^{n} \sum_{j=1}^{C} u_{ij}^{m} \left\| x_i - CH_j \right\|^2 \tag{10}$$

Where *n* is the number of sensor nodes, ***c*** is the number of clusters, x_i is the ith sensor node, CH_j is the j[th] cluster center, u_{ij}^m is the degree of membership of the i[th] sensor node in the j[th] cluster, and *m* is a constant greater than 1 (typically m = 2). $\left\| x_i - CH_j \right\|^2$ represents the measure of the Euclidean distance between the sensor node x_i and the cluster center CH_j.

The degree of membership u_{ij}^m and the cluster Head CH_j are defined as the (11), (12).

$$u_{ij} = \frac{1}{\sum_{k=1}^{c} \left(\frac{\| x_i - c_j \|}{\| x_i - c_k \|} \right)^{\frac{2}{m-1}}} \tag{11}$$

$$CH_j = \frac{\sum_{i=1}^{N} u_{ij}^m . x_i}{\sum_{i=1}^{N} u_{ij}^m} \tag{12}$$

Following are the steps of the fuzzy C-means algorithm

a. Initialize membership u_{ij};
b. Find the fuzzy centroid CH_j for j = {1, 2, 3...c};
c. Update the fuzzy membership u_{ij};
d. Repeat steps II and III until $f(u_{ij}, CH_j)$ is no longer decreasing.

3. FUZZY C-MEANS BASED HIERARCHICAL ROUTING APPROACH (F-LEACH)

Here we present the outline of a fuzzy C-means based hierarchical routing approach (F-LEACH). The sensor nodes are uniformly spread over an area of 100 m2 to track the environment incessantly. Sensor node sensing data is forwarded to BS outside of the deployment area. Each sensor node may either work in sensing

mode to track the parameters of the environment and transmit it to the associated CH or in CH mode to collect, compress, and send data to the base station. Here follow some additional as assumptions:
- The base station has limitless power and computing power and is located outside the sensor area.
- The network is homogeneous and all sensor nodes are static and have the same initial capacity.
- Nodes have the ability to monitor the transmission power in relation to the distance of receiving nodes.
- Links are symmetric

The F-LEACH use three algorithms. Firstly, it starts using the subtractive clustering approach to evaluate the correct number of clusters [32]. The FCM algorithm is then implemented to form highly uniform clustering dispersion of nodes (segmentaion of network). In each cluster, the LEACH protocol is used to build the sub-clusters and choose the head sub-clusters and their members, which apply a pure probabilistic model for CHs selection and periodically rotate the CHs for the energy consumption balance. Figure 1 presents a flowchart of the F-LEACH cluster formation process, which combines the clustering of fuzzy C-means, LEACH, and the subtractive clustering method [33].

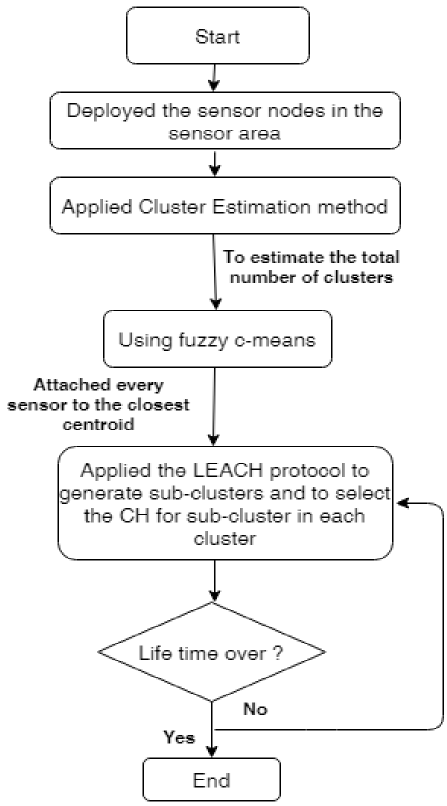

Figure 1. Flowchart of the cluster formation process of the F-LEACH

4. DISTRIBUTED ENERGY EFFICIENT CLUSTERING ALGORITHM BASED ON FUZZY LOGIC APPROACH (F-DEEC)

In this section, we show the distributed energy efficient clustering algorithm system based on a fuzzy logic approach (F-DEEC), which focuses on three approaches to deal with the WSN energy conservation issue [26]. The sensor nodes are randomly distributed in the application area so as to monitor the environment incessantly. Here follow some additional as assumptions: The base station has limitless power and computing power. All sensor nodes are static and have the same initial capacity. Nodes have the ability to monitor the transmission power in relation to the distance of receiving nodes. The F-DEEC model is based on three algorithms. Firstly, it starts to use the subtractive clustering approach for an optimal number of wide clusters. Secondly, the role of the application of the FCM algorithm is to form highly uniform clustering of nodes based on an optimal number generated by the subtractive clustering method. In each cluster, the DEEC protocol is used for the construction of the clusters and to the selection of the CHs and their members. To balance energy consumption, it uses a pure probabilistic model to select CHs and to rotate the CHs periodically. Figure 2 demonstrates the flowchart of the F-DEEC cluster formation process [28].

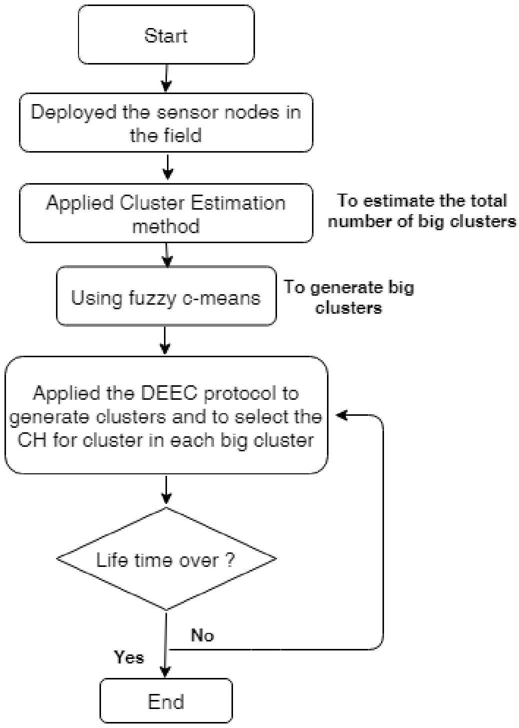

Figure 2. Flowchart of the cluster formation process of the F-DEEC

5. SIMULATION AND EVALUATION

To assess the F-LEACH and F-DEEC energy efficiency, we compared the main performance of the F-LEACH and F-DEEC with the DEEC protocol and the LEACH protocol. All simulations were carried out using MATLAB to evaluate the entire energy system and the number of nodes alive. We began by explaining the metrics used in the simulations. We include the details of the algorithm used, and then present and analyze all the results obtained. For simulation, 100 nodes are assumed to be distributed randomly in an area of (100/100) m; the BS is positioned outside the area at the coordinate (-50, 50). The nodes do not have the same initial capacity, and it is presumed that the base station has limitless power. Throughout each round, each node sends.4000-bit packets to the base station via the head of the cluster.

All the results are displayed in Figures 3-7. Figure 3 shows the number of dead nodes versus the transmission series. The blue-colored curve shows the results obtained by using the LEACH protocol. The results of the DEEC protocol show the red-colored curve; the yellow-colored curve shows the results of F-LEACH and the green color shows the results of F-DEEC protocol. Figure 4 shows the number of live nodes versus the transmission round. This figure has 4 curves: The red curve shows the results obtained in the case where the DEEC protocol is executed; the results of the LEACH protocol shown by the blue curve. The yellow curve shows the results obtained by F-LEACH and the green color shows F-DEEC protocol.

According to Figures 3 and 4, we can observe that protocol prolongs the stability period compared to F-LEACH, DEEC and LEACH protocol. In addition to that, the F-LEACH gives better results in stability period than the DEEC and LEACH. According to Figures 3 and 4, we can note that F-DEEC protocol extends the stability duration compared to protocol F-LEACH, DEEC and LEACH. Furthermore, the F-LEACH provides better results in stability cycle than the DEEC and LEACH. The first dead node for LEACH protocol, DEEC protocol, F-LEACH protocol, and F-DEEC protocol is at 828 rounds, 962 rounds, 1630 rounds, 1896 rounds respectively. Statistics show that the F-LEACH protocol and the F-DEEC protocol are better than the LEACH protocol and DEEC protocol to increase the parameter stability duration. The last dead node to LEACH protocol is at 2720 rounds. For DEEC protocol, one node is live at 4000 rounds, 24 living nodes, 53 living nodes for DEEC protocol, respectively F-LEACH protocol and F-DEEC protocol. Therefore, in the instability period, the F-DEEC protocol proves to be more energy-efficient than the F-LEACH protocol, the DEEC protocol and the LEACH protocol.

With respect to the number of rounds as seen in Figure 4, we have estimated the network lifetime in terms of a number of living nodes. The alive nodes are those with their resources as not null. In the original LEACH protocol, all nodes in the network are dead for the 2720th round. But for the DEEC protocol one node is alive after the 4000th round. In the F-LEACH protocol, the first nodes die in 1630th rounds and after 4000th rounds the 24 nodes are alive. The first nodes in the F-DEEC protocol die in rounds 1896 and the 53 nodes are alive after rounds 4000. Among all these, the F-DEEC protocol offers the longest lifetime of the network that allows a balanced network of loads to be reached. The results obtained in Figures 4 and 5 indicated that the F-DEEC protocol and the F-LEACH protocol supported WSN with the longest lifetime compared to the LEACH protocol and DEEC protocol. It can be observed that protocol F-DEEC and protocol F-LEACH increase the stability duration relative to protocol LEACH and protocol DEEC. The F-DEEC protocol and the F-LEACH protocol prove therefore to be more energy-efficient than the DEEC protocol and the LEACH protocol.

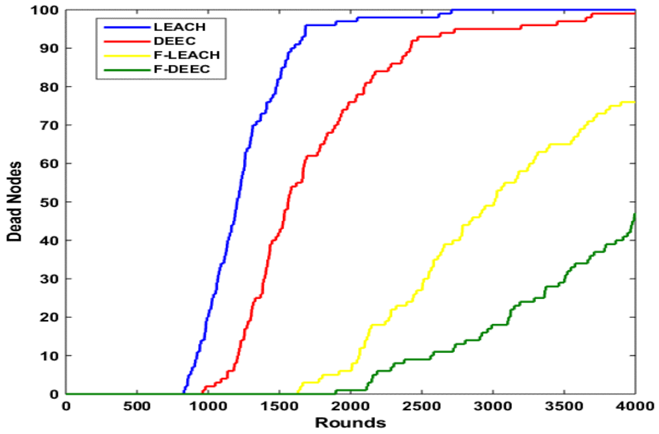

Figure 3. Number of dead nodes versus transmission round

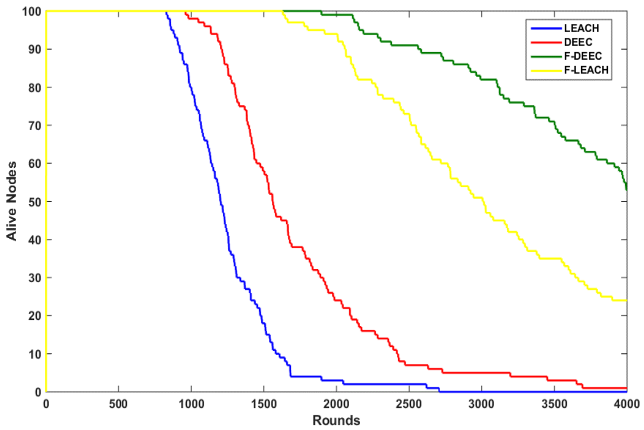

Figure 4. Number of alive nodes versus transmission round

The energy consumption for each transmission round is demonstrated in Figures 5 and 6. In Figure 5, there are 3 curves; the LECH protocol presented by the curve in blue; the red color portrays the DEEC protocol and the curve in yellow shows the result of F-LEACH protocol. Findings for F-DEEC protocol, LEACH protocol, and DEEC protocol are presented in Figure 6. In the case where F-DEEC is implemented, the green curve shows the energy consumption for each point. As for the other curves (the red curve and the blue curve), they have the same behavior of consumption of transmission energy per round.

According to Figures 5 and 6, the first protocol that absorbs more energy than the other protocols during the stability period is LEACH protocol. However, the DEEC protocol consumes less than the LEACH protocol, but more than the F-LEACH protocol and the F-DEEC protocol, while the F-DEEC protocol consumes less than the other three. We have measured the total network energy consumption per round as seen in Figure 7. The blue color indicates the LEACH protocol, the red color represents the DEEC protocol, the yellow color illustrates the F- LEACH protocol, and the green color shows F-DEEC protocol. This quantity refers to the direct volume of energy exhausted in the network per round. Here, the overall energy consumption by the network is 78.48 J, 75.38 J, 71.19 J, and 63.93 J for LEACH protocol, DEEC protocol, F-LEACH protocol and F-DEEC protocol respectively. The performance of the F-DEEC protocol proves to be better than the LEACH protocol, the DEEC protocol, and the F-LEACH protocol. Yet, the F-LEACH protocol expended its energy more than DEEC protocol and LEACH protocol. We can see that F-DEEC protocol decreases the energy consumption by round and increases the network lifetime more than the standard DEEC protocol, the original LEACH, and F-LEACH protocol. Also, the F-LEACH protocol improved the network's lifetime compared to the LEACH and DEEC.

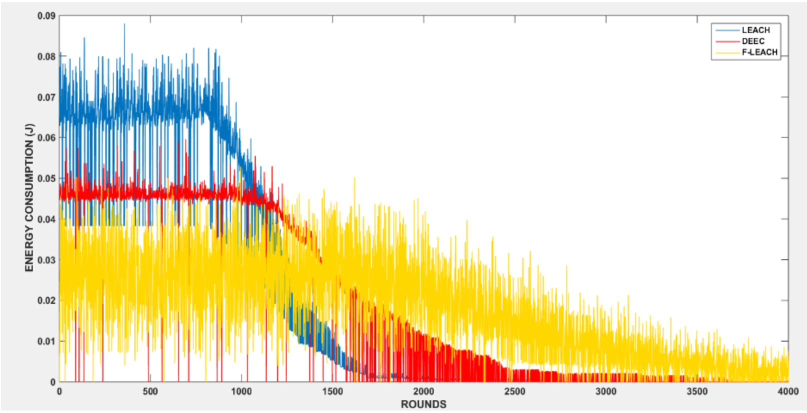

Figure 5. Energy consumption for each transmission round

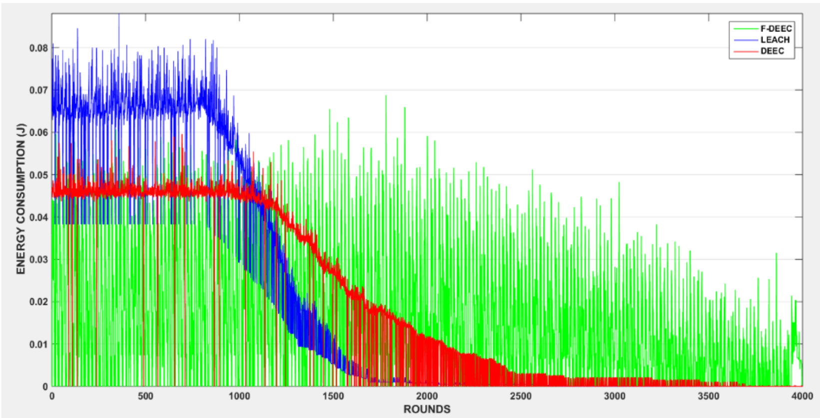

Figure 6. Energy consumption for each transmission round

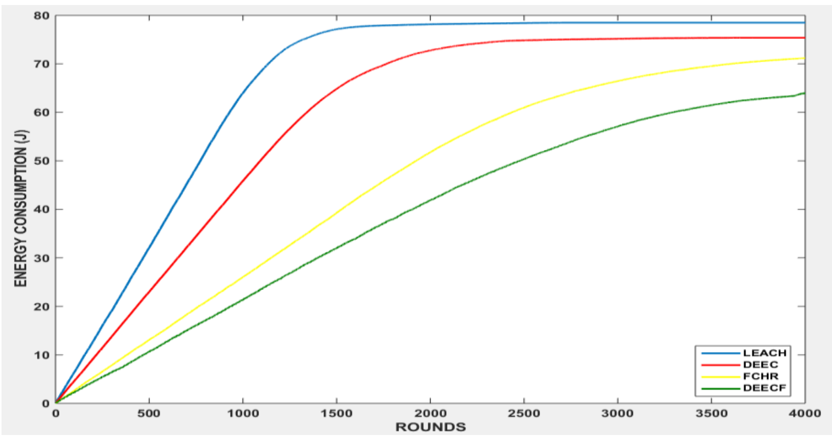

Figure 7. Total energy consumed by the network versus transmission round

6. CONCLUSION

The main objective of this work is to propose tow Hybrid routing protocols based on fuzzy C-means algorithm applied for wireless sensor networks. The proposed routing protocols minimizes the energy consumption, extends the network lifetime of the sensor nodes. Through a comparison of key performance parameters of wireless sensor networks, a solid evaluation of LEACH, DEEC, F-LEACH, and F-DEEC protocols. In this respect, Extensive simulations have been carried out to assess the technical capability of each protocol in relation to the studied parameters. Therefore, the results show that the F-DEEC protocol has proven that its energy-efficiency, reliability and load balancing in the stability and instability periods of the network.

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