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Fog-based Energy-efficient Dijkstra Algorithm for Heterogeneous Wireless Sensor Network

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Abstract: The emergence of the Heterogeneous Wireless Sensor Network (HWSN) has attracted the attention of researchers in recent years. In HWSN, the sensor nodes have different sensing, processing, storage, power, and communication capabilities. Different protocols, algorithms, and applications have been proposed for HWSN. However, several research challenges, for example, efficient utilization of node energy, transmission control, enhancing network lifetime, optimum route selection, and minimizing the delay involved in processing still need to be addressed. The sensor nodes are battery-powered and in most cases, it is impossible to replace the batteries. Hence, it is important to design energy-efficient solutions for HWSN. To improve energy efficiency and increase the lifetime of HWSN, we proposed a fog-based energy-efficient solution called FEDR. The design of FEDR is based on the Dijkstra algorithm. The proposed architecture was implemented in a simulation environment. We performed several experiments to evaluate the performance of FEDR. We also compare the results in terms of alive nodes and energy utilization with two state-of-the-art solutions called ACO-based routing of fog nodes (FEAR) and Pegasis-based Routing of Fog Nodes (FECR). Experimental results showed that FEDR outperforms FEAR and FECR. From the results, we conclude that our proposed solution improves the energy efficiency and lifetime of HWSN.

Keywords: Energy efficiency, Fog computing, FEDR, Heterogeneous wireless sensor network, Network lifetime

1. INTRODUCTION

Heterogeneous Wireless Sensor Network (HWSN) is a special kind of Wireless Sensor Network (WSN). It is composed of small size sensor nodes (either stationary or mobile) with different capabilities. These nodes can sense the surrounding environment and then forward the information using wireless communication. The nodes in HWSN also have storage and on-board processing functionalities. These nodes are battery-powered and have a limited lifetime. The basic responsibility of these nodes is to collect and transmit the information, sensed from the surrounding environment. Normally, the data collected is transmitted towards the sink node using multi-hop wireless communication. The sink node itself is connected to other networks by using a gateway.

Nodes in HWSN have very limited resources. Node Energy is the most essential resource and power consumption by nodes is the primary concern in HWSN. Several factors can increase the power consumption of a node, e.g., transmission range, the distance between the nodes, data gathering and processing, etc.

The sensor node senses the data from the deployed field and then forwarded it to Cluster Head (CH). When the distance between the sensor nodes and CH increases the power of the CH decreases rapidly [1]. Furthermore, about 80 percent of the energy is consumed by a sensor node during the transmission of the data [2]. In HWSN, it is usually impossible to replace the node battery, hence, alternative solutions are required to enhance the lifetime of the network [3].

In HWSN, the CHs are responsible for performing multiple tasks. They collect the data from the nodes, process the collected data, and then send it to the cloud. Hence, the CH consumes a large amount of energy in the transmission of data. Similar to normal sensor nodes, efficient utilization of the energy is also important for the CH. The CH selection strongly influences the performance of the network. Normally, the CH consumes about 20 percent of the energy on data aggregation tasks. If we assign the responsibility of data aggregation to the fog node then it will minimize the energy consumption of the CH and will eventually enhance the lifetime of the network. Furthermore, it will also increase the performance of the network (e.g., transmission control) as the fog node covers more area than a sensor node.

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This work proposed a fog-based energy-efficient solution for HWSN. The proposed solution is known as FEDR. In our solution, fog nodes play an important role. The fog nodes have greater storage, processing, communication, and energy capabilities. Unlike the normal sensor nodes, fog nodes have no energy constraints. The fog nodes collect the data from the CHs and forward it to the cloud. For this purpose, we used the Dijkstra algorithm. Dijkstra is a well-known shortest path algorithm. The basic idea for the fog nodes is to decrease the network load on the CHs and improve the lifetime and performance of the network.

A. *Objectives*

The general objective is to improve energy efficiency in HWSN by using fog nodes. To this end, the more specific objectives are:

- To propose a Dijkstra algorithm-based solution for fog-assisted HWSN.
- To increase the lifetime of HWSN by efficiently preserving the energy of the nodes.
- To improve the overall performance and efficiency of the HWSN.

The remaining of this article is organized as follows: The literature review is given in the next section. Section 3 provides a simplified architecture of our proposed solution. The simulation environment and some relevant parameters are discussed in section 4. The results and discussion is provided in section 5. Lastly, section 6 concludes this article with several future research directions.

2. Literature Review

In the literature, different algorithms and protocols have been proposed to increase the battery life of sensor nodes. Low-Energy Adaptive Clustering Hierarchy (LEACH) is a well-known cluster-based energy-efficient and scalable protocol for WSN. LEACH is a load balancing protocol that selects the node with high energy to become a CH. The CH is responsible for handling the data of a particular cluster. The limitation of the LEACH protocol is that it is designed for homogeneous WSN. In addition, the CH in LEACH protocol consumes more energy, as compared to the normal sensor nodes. However, LEACH can randomly select alternative nodes to become CH. Lastly, the adaptive nature of cluster creation could lead to a poor configuration of the network [4].

Another protocol called LEACH-Centralized (LEACH-C) is proposed to address the limitations of the LEACH protocol [5]. In this protocol, the clusters are formed with the coordination of a Base Station (BS). The main advantage of LEACH-C is that it minimizes the consumption of energy used by the sensor nodes to form the cluster. In addition to that, the centralized algorithm can lead to better cluster creation and management. The main disadvantage of this protocol is the overhead in the formation of clusters. Also, LEACH-C is not recommended for large scale networks.

To further enhance the performance of the LEACH protocol, LEACH with Deterministic Cluster-Head Selection (LEACH-DCHS) was proposed in [6]. The main objective of LEACH-DCHS protocol is to extend the lifetime of the network. To achieve this objective, the LEACH-DCHS protocol makes changes to the original LEACH protocol. As a result, it increases the lifetime of the network by 30 percent. In the LEACH-DCHS protocol, the cluster head is selected by measuring the probability of the remaining energy of each node. The main disadvantage of this protocol is the degradation of the network performance, due to cluster formation.

Another LEACH-based protocol, called Power Efficient Gathering in Sensor Information Systems (PEGASIS), was introduced in [7]. PEGASIS is a chain based routing protocol in which each sensor node establishes a connection with the neighbor nodes. This protocol allows any node to become the CH. Also, all the nodes can send and receive information to the BS to achieve a balanced network energy mechanism. It also improves the overall lifespan of the network. However, this approach introduced extra overhead, due to frequent changes in the cluster head. Also, it was designed keeping in view the requirements of homogeneous WSN, where the nodes have equal energy and processing capabilities. In addition, PEGASIS requires the sensor nodes to have the global knowledge of the underlying network. This limits its functionality to fixed network topology.

The Prolong-Stable Election Protocol (P-SEP) is designed to enhance the stability period of HWSN. P-SEP makes use of Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) protocols to overcome the inter and intra cluster collisions. P-SEP estimates the remaining energy of the sensor nodes. Based on this information it can ignore the nodes with a lower remaining energy to become the CH. P-SEP may introduce extra delay during data transmission and reception [8].

In [9], the authors proposed Particle Swarm Optimization with Energy-efficient Clustering and Sink Mobility (PSO-ECSM) protocol for improving energy efficiency. The PSO-ECSM algorithm is designed to address the challenges of sink node mobility and CH selection. It takes into consideration several factors like, remaining energy, distance to the CH, and cluster size. The sensor nodes were divided into three categories, i.e., normal, advanced and super sensor nodes. Simulations were performed to evaluate the performance of the proposed scheme. Different parameters were used for the cluster head selection, such as residual energy and degree of a node. The main limitation of PSO-ECSM is the mobility restrictions imposed on the sensor nodes. Besides from sink nodes, the rest of the sensor nodes are static. Another limitation is that the sensor nodes are not aware of their locations.

To improve the energy efficiency of WSN, LEACH with Dijkstra's Algorithm (LEACH-DA) is proposed in [10]. The proposed solution enhanced energy efficiency by selecting the shortest path by using Dijkstra's algorithm. For load balancing, they adopt clustering strategies to calculate the traffic and select the appropriate paths. They considered the cloud and fog computing paradigm for the implementation of the LEACH-DA in MATLAB, however, The architecture of the proposed solution was not provided. Furthermore, the design of LEACH-DA is proposed for homogeneous WSN only.

Another Dijkstra-based solution is presented in [11]. The proposed solution uses a multi-hop transmission strategy for WSN. They use two methods for the selection of cluster head. The first criteria for the cluster head selection are to make sure that the selected node can easily communicate with the neighbor nodes. The second criterion is to select the node which has maximum coverage for transmission. After the selection of the cluster head, the algorithm classifies the active and sleeping nodes. The results conclude that multi-hop transmission is better than single hop transmission. The authors do not perform any simulations or real world experiments. rather, they rely on mathematical modeling to provide a proof of concept.

The work in [12] proposed another energy-efficient protocol called Straight Line Routing (SLR). The SLR considers the distance between two points as a straight line. This straight line between any two points represents the shortest distance. However, in some situations the path to the destination will not always be available. Another drawback of the SLR approach is the overhead involved in finding the shortest path.

The authors in [13] proposed Power-Efficient Routing for In-Network Data Aggregation (PALDA), which is an Ant Colony Optimization (ACO), and Local Minimum Spanning Tree (LMST) based energy efficient protocol for WSN. The proposed solution defines the structure of routing and improves the data aggregation and transmission power of wireless sensor nodes. They also proposed an algorithm for the formation of a cluster, and the selection of a cluster head. The performance of PALDA was evaluated using JSim and the results were compared with two other well-known protocols. The obtained results show the efficiency of the PALDA in terms of transmission power, packet overhead, aggregation rate, and energy consumption.

To enhance the lifetime of WSN and decrease energy utilization, the authors in [14] proposed a Hybrid Integrated Clustering Algorithm (HICA). The design of HICA is based on the concept of distributed clustering mechanism. Each cluster has a CH which collects and processes data from sensor nodes in the field. In addition, the cluster also contains grid nodes, which are used to forward the aggregated information towards the BS. The performance of the HICA was evaluated in the NS-2 simulator. The results were compared with two other protocols. The simulation results reveal the efficiency of HICA in terms of network lifetime, energy consumption, and throughput.

An energy-efficient cluster head selection protocol for HWSN is presented in [15]. The proposed solution is called Energy Efficient Cluster head Selection Scheme (ECSS). The ECSS consider the remaining nodes energy for the selection of CH. For this purpose, it make use of a threshold function. This mechanism not only improves the network performance but also efficiently utilizes the network resource. To implement and evaluate the performance of ECSS, MATLAB was used. The results were compared with other solutions. The overall results conclude that the proposed ECSS protocol enhanced the overall lifespan, throughput, and energy usage in HWSN.

In [16], the authors proposed an energy-efficient routing scheme called Energy-Efficient Cooperative Routing Scheme for Heterogeneous Wireless Sensor Networks (EERH). In addition, they also present a detailed architecture of EERH. In EERH, the paths for sending packets are established dynamically. The decision for routing paths is based on the residual energy of sensor nodes,propagation delay, distance, and the directions of transmitted packets. Simulation experiments were conducted to evaluate the performance of EERH in terms of energy and lifetime of the network. The results of the simulations were compared with two others schemes. It was concluded that the proposed EERH increase the lifetime of the HWSN.

Inspired by [10], and [11], we used the Dijkstra algorithm for routing. However, we extend the use of the Dijkstra algorithm to fog-assisted HWSN. Unlike the existing solutions in literature, we integrate the Dijkstra algorithm, fog computing and HWSN to improve the energy-efficiency, and lifetime of the network. Furthermore, we used a more realistic simulation environment for performing experiments.

3. Architecture of FEDR

In this section, we present our architecture and its main entities. The proposed architecture is also depicted in Figure 1.

A. *Sensor node*

The sensor nodes interact with the environment in order to sense and record some data. Every single node has a power, sensing, processing, and transmission unit. The sensed data is then forwarded to the CH. In our architecture, we used heterogeneous sensor nodes. We used two different types of nodes. The normal (white color) and advanced (gray color) nodes. The advanced nodes have greater capabilities as compared to the normal nodes.

B. *Cluster head*

A CH is a special node that collects data from the sensor nodes, aggregates the data, and sends it to the BS. The

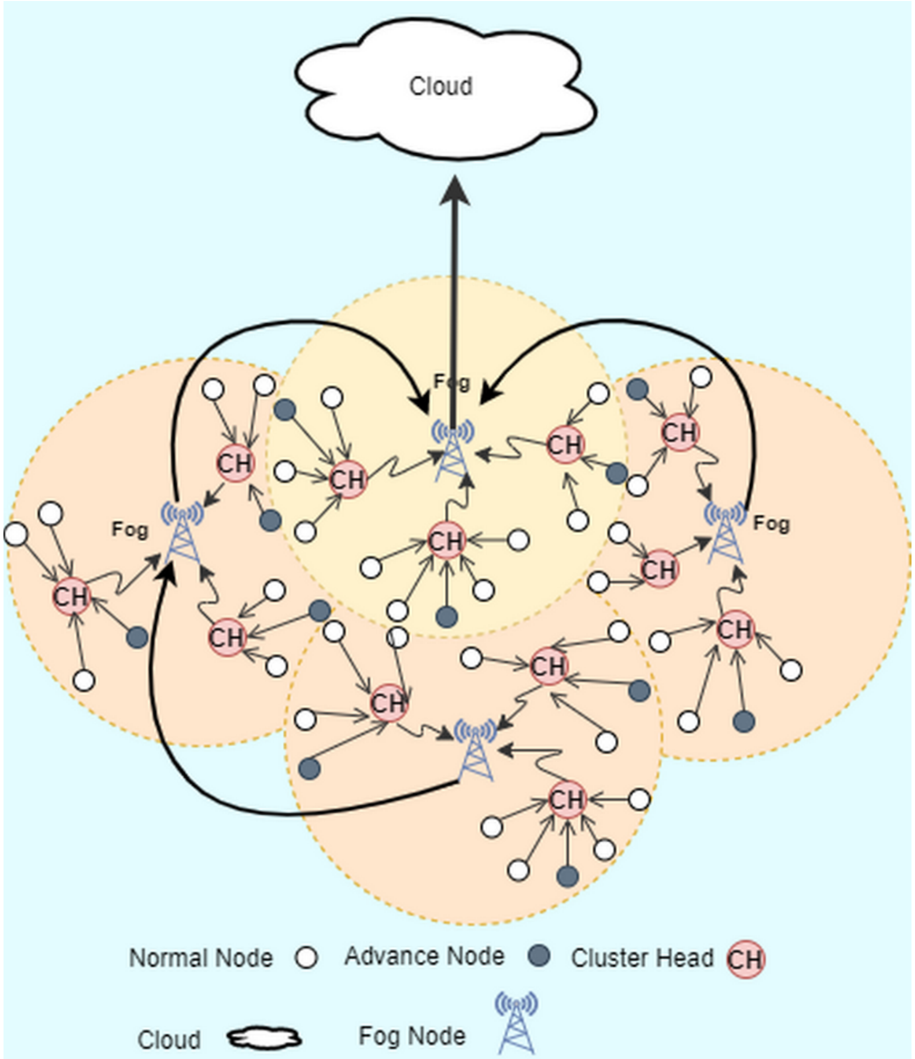

Figure 1. FEDR Architecture

CH is selected based on its characteristics, e.g., residual energy, and distance. In our proposed architecture, the CH is responsible for multiple tasks. First, it communicates with the fog and sensor nodes. Second, it aggregates the received data. Third, it acts as a gateway for the sensor nodes.

C. *Fog node*

A fog node plays an important role in our proposed HWSN architecture. In our architecture, we placed four fog nodes at different predetermined locations. The fog nodes are located between the CHs and the cloud. CH normally collects the information from the sensor nodes and sends it to the fog node. The fog nodes can send the data to the cloud for future use. The area covered by each fog node is known as the coverage area of that fog node [8]. In our architecture, the Dijkstra algorithm was utilized for communication between fog nodes and the cloud. Unlike the sensor nodes, the fog nodes do not have energy restrictions. The basic idea behind the use of fog nodes is to perform data processing locally in the close proximity of sensor nodes. The use of fog nodes minimizes the delay that is involved in the cloud computing paradigm. It also provides a means for reliable communication.

In this architecture, there exist different types of communication. Normally, the data collected by normal and advanced nodes send towards the respective CH. Each CH forwards the data to the fog unit for further processing. The Fog nodes are also responsible for data aggregation. Besides this, the fog nodes are also connected with the cloud by using the Internet as a backbone. However, for our experiments, we focused only on the energy efficiency and the lifetime of the network.

4. Simulation Setup

To implement, test, and evaluate the performance of FEDR, we used MATLAB. MATLAB is a widely used tool that contains numerous scientific packages for mod-

TABLE I. Simulation parameters and values

Parameter	Value
Total geographical area *(A)*	$500m^2$, $1000m^2$
Total number of nodes *(N)*	500, 1000
Total number of normal nodes *(n)*	350, 400, 450, 700, 800, 900
Total number of advanced nodes *(a)*	50, 100, 150, 200, 300
Total number of fog nodes *(f)*	4
Percentage of advanced node *(Pa)*	10%, 20%, 30%
Energy coefficient (α)	3
Initial energy of normal nodes*(En)*	0.5 J
Initial energy of advanced nodes *(Ea)*	En (1 + α)
Initial energy of fog nodes *(Ef)*	25 x En
Initial position of CH	0.1
Communication range of nodes	5.28 m
Total number of Rounds *(r)*	4500, 6000

eling and simulation of different protocols, algorithms, and prototypes. We performed an extensive set of simulation experiments for evaluating the performance of the proposed solution. We also compare the results of FEDR with two other solutions in the literature called ACO-based routing of fog nodes (FEAR) and Pegasis-based Routing of Fog Nodes (FECR).

For our experiments, we consider geographical area of 500 m x 500 m and 1000 m x 1000 m. The number of sensor nodes (both normal and advanced) was kept to 500 and 1000, during the experiments. The normal nodes were deployed randomly, while the location of advanced nodes was predetermined. Besides, the location of fog nodes was also determined in advance.

A. *Simulation parameters*

The main objective is the improvement of the network lifetime by reducing the energy utilization of the sensor nodes. To achieve this goal, we performed different experiments to test the performance of our proposed solution. For this purpose, we consider several parameters for our experiments. The total geographical area *(A)* was kept to 500 m x 500 m and 1000 m x 1000 m. The number of rounds *(r)* was set to 4500 and 6000 for our experiments. The total number of fog nodes *(f)* was fixed to four. The total number of sensor nodes (both normal and advanced) is represented by N, where the number of normal is denoted by n, while the number of advanced nodes is denoted by a respectively. The parameter Pa represents the percentage of advanced nodes. The energy of the normal node is denoted by En, while the energy of the advanced node is Ea. Moreover, the energy of the fog node is Ef. Inspired by [17], the communication range of sensor nodes was set to 5.28 m. The complete list of the most relevant parameters and their values is given in Table 1.

We evaluate the performance of our proposed solution by designing two different types of scenarios. For the first scenario, we considered A= 500 m x 500 m, N=500 and r=6000. For the second scenario, we set A= 1000 m x 1000 m, N=1000, and r=4500. In both of these scenarios, the value of f was fixed to 4. Furthermore, these fog nodes were deployed in predefined locations.

5. RESULTS AND DISCUSSION

The results of our experiments are discussed in this section. We also present the results of the comparison of our proposed solution with FEDR and FECR. We divided our experiments into the following two subsections.

A. *Network life time*

In this set of experiments, we evaluate the performance of our proposed solution in terms of network lifetime. For the first series of experiments, we considered A=500 m x 500 m, N=500, r=6000, and Pa=10%, 20%, and 30%. The results for the Pa=10%, Pa=20%, and Pa=30% are shown in Figures 2, 3, and 4 respectively.

Figure 2 shows the results of the first case (where Pa=10%). It is observed that the number of alive nodes

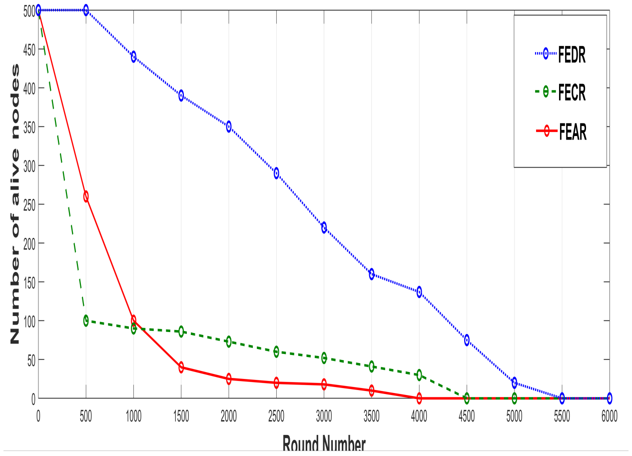

Figure 2. Number of alive nodes(A=$500m^2$, N=500, Pa=10%)

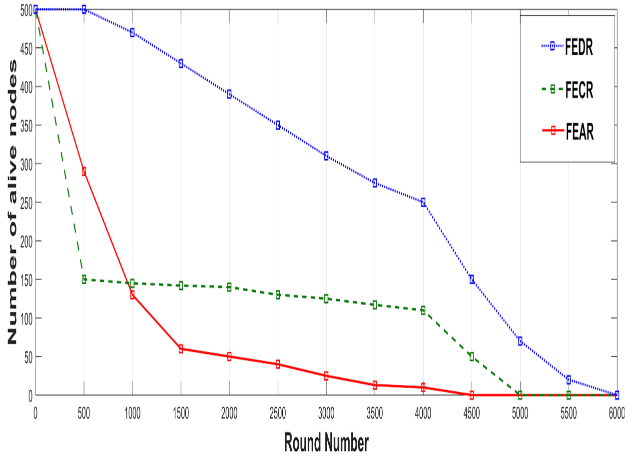

Figure 3. Number of alive nodes(A=500m^2, N=500, Pa=20%)

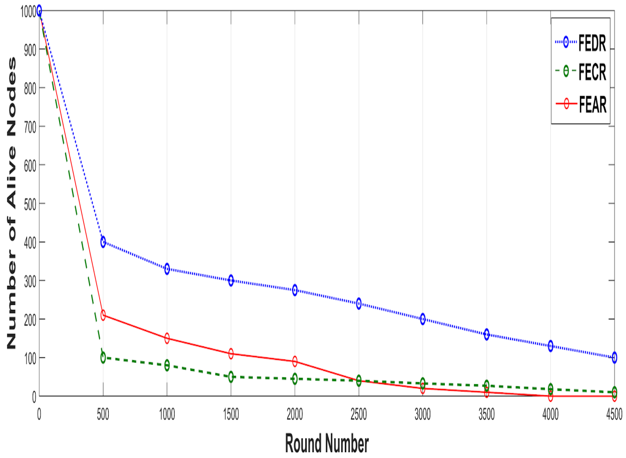

Figure 5. Number of alive nodes(A=1000m^2, N=1000, Pa=10%)

in FEAR reaches zero at r=4000. In the case of FECR, the number of alive nodes reaches zero at r=4500. However, in our case, the number of alive nodes reaches zero at r=5500.

In Figure 3, the results of the second case (i.e., Pa=20%) are shown. Here, the number of alive nodes in FEAR is zero at r=4500. In the case of FECR, the number of alive nodes reaches zero at r=5000. In our case, the number of alive nodes reaches zero only at r=6000.

Finally, the results of the third case (i.e., Pa=30%) are shown in Figure 4. The graph reveals that the number of alive nodes in FEAR is zero at r=4500, while it is zero at r=6000 in FECR. In our case, the number of alive nodes is still above zero at r=6000.

In this second series of experiments, we changed the values for parameters A, N, and r. Here, we considered A=1000 m x 1000 m, N=1000, r=4500, and Pa=10%, 20%, and 30%. The results for the Pa=10%, Pa=20%, and Pa=30% are depicted in Figures 5, 6, and 7 respectively.

For Pa=10%, the results are shown in Figure 5. The results clearly show that for the FEAR and FEDR, the number of alive nodes is closed to zero at r=3000. However, in the case of FEDR, the number of alive nodes is still 100, even after r=4500.

In Figure 6, the results of the second case (i.e., Pa=20%) are shown. Here, the number of alive nodes in FEAR is zero at r=4000. Comparatively, the FECR outperforms as the number of alive nodes is 100, even after r=4500. Finally, the performance of FEDR is much better as more than 200 nodes were still alive after r=4500.

The results for the third case (i.e., Pa=30%) are shown in Figure 7. At r=4500, the number of alive nodes is less than 200 for FEAR and 300 for FECR. However, the performance of FEDR is better than FEAR and FECR, as the number of alive nodes is still above 400 after r=4500.

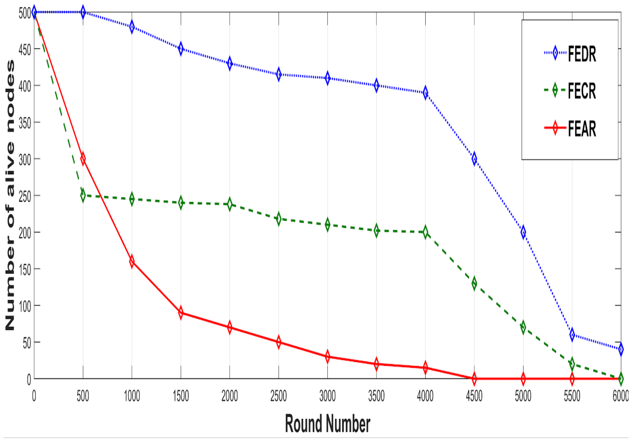

Figure 4. Number of alive nodes(A=500m^2, N=500, Pa=30%)

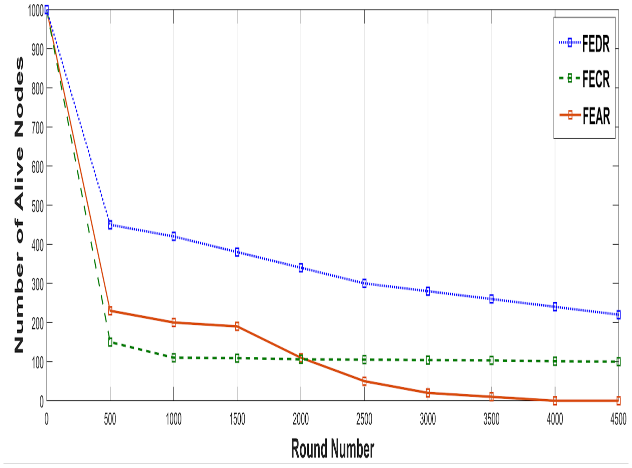

Figure 6. Number of alive nodes(A=1000m^2, N=1000, Pa=20%)

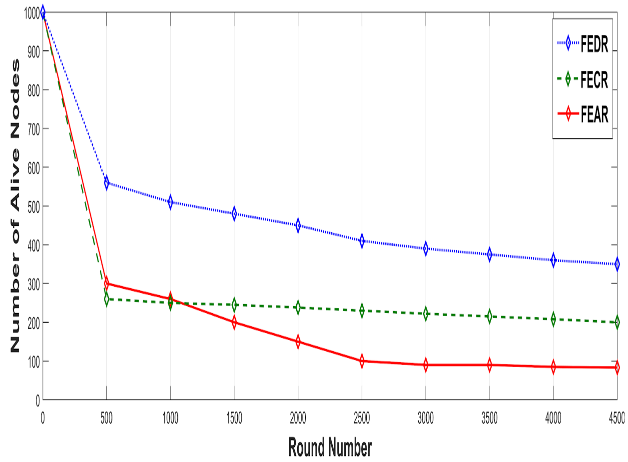

Figure 7. Number of alive nodes(A=1000m^2, N=1000, Pa=30%)

From the results, it is clear that the network lifetime increases when the percentage of the advanced nodes increases. Comparatively, our proposed solution performs better, in terms of node lifetime for different values of *Pa*.

B. Average energy of nodes

In these experiments, we evaluate the performance of our proposed solution in terms of average energy of nodes. We divided our experiments into two subsets. For the first series of experiments we considered A=500 m x 500 m, N=500, r=6000, and Pa=10%, 20%, and 30%. The results for the Pa=10%, Pa=20%, and Pa=30% are shown in Figures 8, 9, and 10 respectively.

Figure 8 shows the results of the first case (i.e., Pa=10%). In the case of FEAR, the average energy of nodes falls rapidly, as it reaches 0 J at r=4000. In the case of FECR, the energy level reaches 0 J at r=5000. However, the FEDR outperforms in terms of energy, as it reaches 0 J, after r=6000.

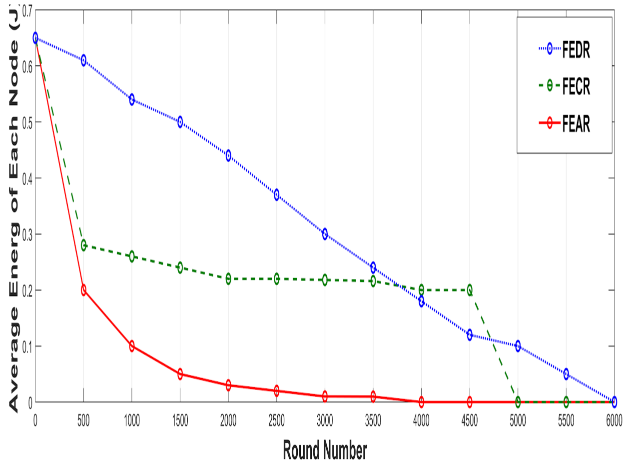

Figure 8. Remaining energy(A=500m^2, N=500, Pa=10%)

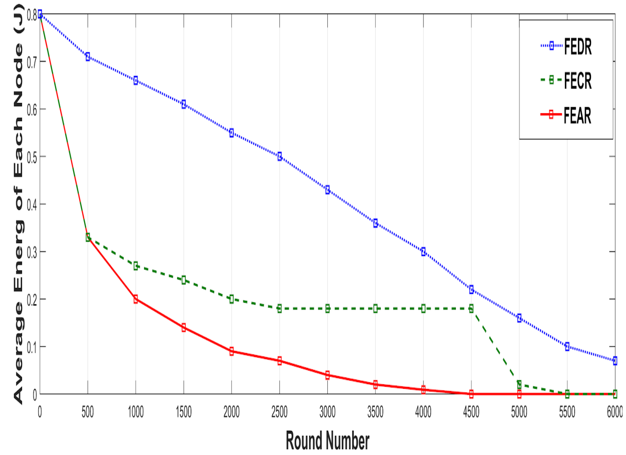

Figure 9. Remaining energy(A=500m^2, N=500, Pa=20%)

In the second set of experiments, we changed the value of *Pa* to 20%. The obtained results are shown in Figure 9. In the case of FEAR, all the nodes are dead at r=4500. While, in the case of FECR, the energy of all nodes reaches 0 J at r=5500. On the other hand, the performance of FEDR is much better. Firstly, it shows a very smooth behavior. Secondly, the remaining nodes are still above 0 J, after r=6000.

In the third set of experiments, we changed the value of *Pa* to 30%. The results are depicted in Figure 10. It can be observed that the FEAR performance is below the other solutions. In this case, the total energy reaches 0 J at r=4500. The same is the case for FECR, where the energy also reaches 0 J at r=4500. However, like the previous results, FEDR shows better performance. In this case, the remaining node's energy is still 0.1 J, even after r=6000.

In this second series of experiments, we have changed the values for parameters A, N, and r. Here, we considered

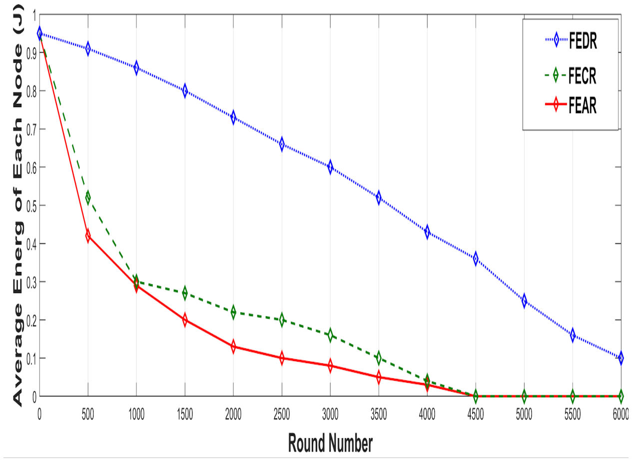

Figure 10. Remaining energy(A=500m^2, N=500, Pa=30%)

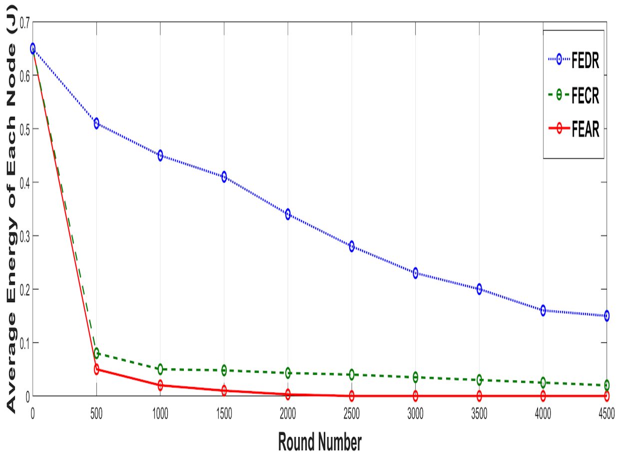

Figure 11. Remaining energy(A=1000m^2, N=1000, Pa=10%)

A=1000 m x 1000 m, N=1000, r=4500, and Pa=10%, 20%, and 30%. Theresults for the Pa=10%, Pa=20%, and Pa=30% are depicted in Figures 11, 12, and 13 respectively.

Figure 11 shows the results of the first case (i.e., Pa=10%). In the case of FEAR, the average energy of nodes falls rapidly, as it reaches 0 J at r=2000. In the case of FECR, the energy level still remains above 0 J at r=4500. Yet, the FEDR outperforms in terms of energy, as the remaining energy is still 0.2 J at r=4500. It will allow the network to run and operate for a longer period.

In the second set of experiments, we changed the value of Pa to 20%. The obtained results are shown in Figure 12. In the case of FEAR, the average energy of the node is almost 0 J at $r=4500$. However, the FECR shows better performance, as the energy level is still 0.1 J at r=4500. For the same value of r, the FEDR energy level is still very high, i.e., 0.3 J.

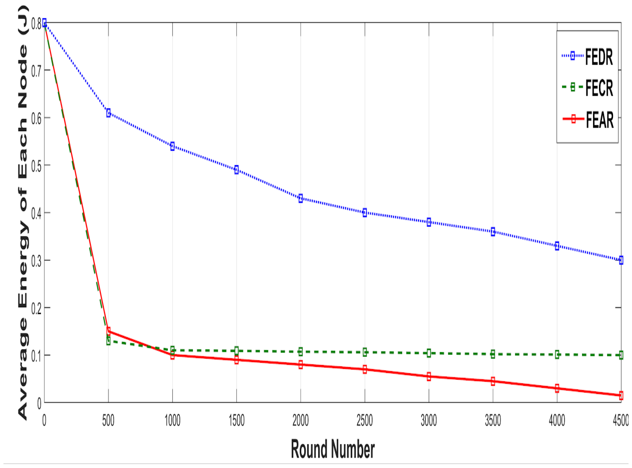

Figure 12. Remaining energy(A=1000m^2, N=1000, Pa=20%)

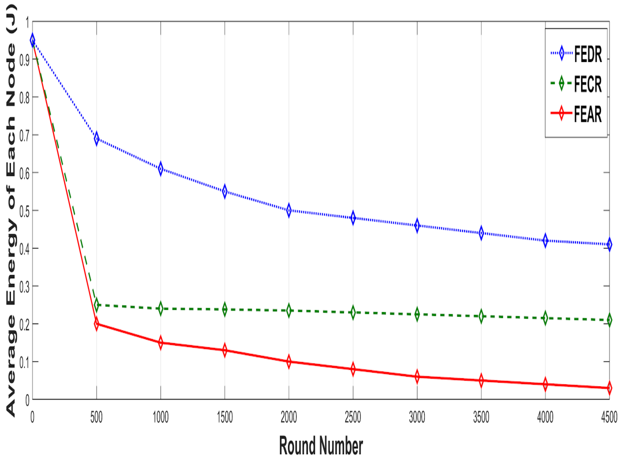

Figure 13. Remaining energy(A=1000m^2, N=1000, Pa=30%)

In this final set of experiments, we changed the value of Pa to 3%. The results obtained are given in Figure 13. As expected, the performance of the proposed solution was further enhanced due to an increase in the number of advanced nodes. From the results, it is clear that in the case of FEAR the energy level of each node is almost 0 J at r=4500. However, the energy level of FECR is still 0.2 J at r=45000. Comparatively, our proposed solution has more remaining energy (i.e., 0.4 J) at r=4500.

From the results, it is concluded that as the number of rounds increases, the energy of nodes decreases accordingly. In all cases, our proposed solution (FEDR) provides better results in terms of remaining energy, as compared to the FEAR and FECR. The main idea behind this improvement is the use of fog nodes, which receive the data from CHs and process it. It is further concluded that the proposed solution generally has lower energy consumption and can enhance network lifetime and performance.

6. Conclusion and Future Work

This paper proposes FEDR, an energy efficient, fog-based solution for HWSN. We also presented the architecture of the proposed solution. The architecture consists of normal, and advanced nodes. It also contains CH and fog nodes. The fog nodes were also connected with the cloud infrastructure by using the Internet as a backbone. Furthermore, we implement and evaluate the performance of FEDR by extensive simulation in MATLAB. Besides, we also compare the results of FEDR with FEAR and FECR. The results demonstrate the efficiency of the proposed solution in terms of energy efficiency and improved network lifetime. The results show the importance of fog nodes in the HWSN. It further reveals that the ratio of advanced nodes can dramatically improve the performance of the overall network.

Currently, we are working on the routing aspects of the proposed solution. More specifically we are focusing on how to find an efficient route for data communication among fog nodes and the cloud. In addition, we are also working on the security aspects of communication among CHs and fog nodes. Besides, we are trying to explore how the broadcast frequency of nodes, transmission power, and multi-hop communication affect the energy consumption of nodes.

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