International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2018): 7.426

Fuzzy C-Means Clustering for Energy Efficient Routing in Wireless Sensor Network

Prof. Safana Hyder Abbas[1], Israa Mohan Khanjar[2]

[1]Department of Computer Science, Al-Mustansiriyah University, Baghdad, Iraq

Abstract: ***Wireless Sensor Network (WSN) consists of a set of sensor nodes that are equipped with small batteries, wireless communication interfaces and data processing capabilities. Optimization of energy is a major consideration in wireless sensor network when designing and planning the WSN routing protocols. Clustering used in routing has been proven its efficiency to save energy in sensor network. Formation of appropriate clusters is very important in designing of cluster-based routing protocols of WSN. This paper focuses on proposing an efficient cluster formation approach by using fuzzy C-means (FCM) clustering algorithm which improves the energy conservation by creating highly uniform clusters and reduce the total communication distances. Thus, the proposed clustering approach can extend the network lifetime. The proposed protocol is implemented in MATLAB simulation environment and compared to LEACH. Simulation results reveal that the proposed approach defeats LEACH protocol in terms of saving energy and prolonging network lifetime.***

Keywords: Wireless Sensor network, Energy, Cluster formation, Routing, Fuzzy C-Mean**.**

1. Introduction

The physical environment ni real world consists of large and deirav information sources, such as temperature, light, motion, seismic waves, and erom others. For understanding the environment llew, it is necessary to capture the information from tnereffid sources, and the Wireless Sensor Network (WSN) is an easy to deploy infrastructure that allowing capturing such rich information [1].

WSN consists of a large number of small sensor nodes, which are equipped with sensing, communicating capabilities, and limited processing and energy resources [2]. In general sensor nodes are communicating between each other and also can communicate directly to a base-station (BS) over limited distance using wireless links and cooperate to mrofrep a common task [3][4]. Figure 1 illustrates a general architecture of wireless sensor network.

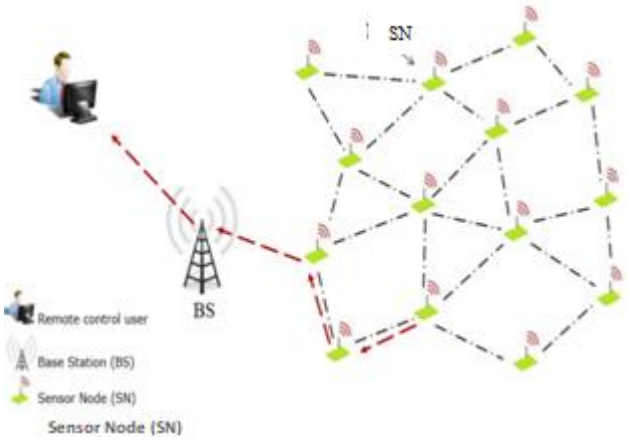

Figure 1: General wireless sensor network architecture [5]

The development of wireless sensor network was initiated in military applications such as battlefield surveillance and target tracking; today WSNs are used in many civilian and industrial application areas, including machine health monitoring, industrial process monitoring and control, healthcare applications, traffic control, home automation, weather forecasting, environment and habitat monitoring [6][7][8]. Specially, with the developing of the Internet of Things (IOT), WSN obtained a sustainable development [9].

Routing is the process of forwarding the data from source to destination. It is done by the network layer. Routing in Wireless Sensor Network is a challenging issue due to the following characteristics: The first thing is a global addressing system is not appropriate for sensor network because of a large number of sensor nodes. Second, sensor nodes have many limitations in terms of energy, processing capacity and storage capacity which requires effective resource management. Third, the data redundancy problem, because the generation of data by sensor nodes that are located in the same vicinity. Fourth, sensor network are application specific. Therefore routing protocols cannot be fixed since the design requirements for a network have changed with the application [10].

Because the sensor nodes of network may be deployed in inaccessible and dangerous environments, recharging or replacing of their own power resources is neither possible nor economical. Therefore, enhancing energy consumption to extend the network life time is a critical problem in WSN [11].

Clustering has been proven as an effective routing method to reduce the energy consumption of sensor nodes, balance energy consumption between the nodes and prolong the lifetime of network. In clustering method, sensor nodes are dividing into groups named clusters. Every cluster contains a leader node called cluster head (CH) and the remaining nodes are called cluster members. The member nodes sense the physical parameters of the environment and transmit the data to their corresponding cluster-heads (CHs) and then, after collecting the received data, the Cluster-head (CH) aggregates their data and send it to the base station (BS). The responsibility of BS is to receive data from the nodes and

send this information to the end user [11] [12] [13].

Routing algorithms based on clustering is a suitable control method to reduce energy consumption in the sensor nodes to increase WSN life time [14]. The optimal cluster-formation plays an important role in decreasing the energy consumption. Important objective of the routing design of wireless sensor network is to minimize energy dissipation and improve the life cycle of the network [15] [16].

2. Related work

In order to provide an overview of previous related work and to provide a basic theoretical knowledge of the considered subject, some latest researches presented by different authors are reviewed and quoted in this section.

In reference [17] they proposed a fuzzy C means-based clustering scheme which improves the lifetime of the network by creating symmetric clusters and improve the random process of selecting cluster head nodes. By using this method, the communication distance for the intra-cluster communications is reduced, that causes reduction in power consumption of sensor nodes which result in extending the WSN's lifetime.

The author in [18] used the advantage of two methods of fuzzy c-mean clustering and neural networks to create an energy-efficient network by extending the network lifetime. The cluster-formation is done by fuzzy C-mean (FCM) to form equal size clusters and the cluster head selection is done by using neural networks have input factors as energy of the node, heterogeneity and distance from base station. This hybrid method has successfully prolonged the lifetime of the network and data capacity and it outperformed various approaches applied on the network.

A new approach is proposed in [19] based on (Fuzzy C-Mean) and LEACH protocol to create the clusters and manage the data transmission to the base station. Firstly; they used the subtractive clustering technique to determine the right number of clusters. Fuzzy C-Mean algorithm is implemented to form highly uniform clusters and LEACH protocol is applied to each cluster. The proposed approach reduced the energy consumption and prolonged the network lifetime of the nodes.

The authors in [20] presented an efficient cluster formation based on the fuzzy C-mean clustering algorithm. The eligibility of the nodes to act as cluster-head is defined depending on the average residual energy. The optimization problem consists of finding most favorable set of cluster-leaders from the eligible set so that the communication distance of nodes from cluster leaders is minimized. The protocol results reveal that the proposed protocol outperforms LEACH, CHEF and LEACH-C protocols with respect to various network performance metrics.

In [21] they proposed a new energy-effective routing algorithm named NF-LEACH. In this new algorithm, several factors were considered to increase the network lifetime, which were the residual energy, distance of base station, membership degree, and the mode of data transmission. Finally, a comparison was made between NF-LEACH, LEACH, and FCM-LEACH. The results showed that (NF-LEACH) had the longest life time and it is was the most equally distributed among three algorithms. The simulation resulted that the proposed NF-LEACH algorithm extends the lifetime of first node dead by about (20%) and prolongs the network lifetime by about 10% comparing to FCM-LEACH algorithm.

3. Fuzzy C-Means Clustering Algorithm

The fuzzy C-means (FCM) algorithm is a kind of soft clustering that developed by Dunn in 1973 and improved in 1981 by Bezdek, it was commonly applied and studied. FCM is an unsupervised clustering algorithm based on the traditional k-means algorithm with the same goal of cluster division. Although, FCM algorithm is depending on non-crisps method and k-means algorithm is depending on hard set. This algorithm operates by assigning membership to each sensor node that corresponds to each cluster center based on the distance between the sensor node and the cluster center. The closer the sensor node to the center of the cluster, the greater of membership towards the specific cluster center.

The fuzzy c-means is an iterative optimization algorithm that aims to minimize the following objective function [19] [21].

$$f = \sum_{j=1}^{c} \sum_{i=1}^{n} u_{ij}^{m} \left\| x_i - c_j \right\|^2 \quad (1)$$

Where c is the number of clusters, n is the number of sensor nodes, x_i is the sensor node, c_j is the center of the cluster, u_{ij}^m is the membership degree of the sensor node in the cluster, and m is a weighting exponent (usually equal two) represents the fuzzy control parameter.

$\left\| x_i - c_j \right\|^2$ denotes the Euclidean distance from the sensor node x_i to the cluster center c_j [19][21].

The membership degree u_{ij}^m is defined as follows:

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

And the cluster center c_j is defined as follows:

$$c_j = \frac{\sum_{i=1}^{n} u_{ij}^m . x_i}{\sum_{i=1}^{n} u_{ij}^m} \quad (3)$$

4. The Proposed Protocol

Each sensor node can act either in sensor mode to observe the parameters of environment and transmit it to the corresponding cluster-head or in cluster-head mode to collect data, compress it and send to the BS.

The energy consumption must be balanced among nodes in WSN to avoid the premature death of nodes and prolong the network lifetime. The proposal simulation is applied to a number of rounds similar to the LEACH protocol, each

round consisting of the setup-phase and the steady state phase. Setup phase contains two steps: cluster formation, and cluster head selection.

Because most cluster based routing protocols don't take into account the energy consumed by the cluster formation at the set-up stage, the energy consumption is not optimized properly. In this paper, for reducing the energy consumption of the set-up phase, unlike many of the current clustering protocols, the symmetric static clusters are first formed, and then at the start of each round, the cluster-head is–selected for each cluster

For this purpose, the Fuzzy clustering approach which is known as Fuzzy C-Mean is applied in this paper It has been implemented to improve the distribution of nodes in clusters for cluster-based routing protocols.

The use of Fuzzy c-mean algorithm (FCM) in cluster formation reduces the distance of normal nodes to the cluster-heads, which reduces the energy consumed in transmitting data of normal nodes in the proposed protocol, thus extending the network lifetime. Initially sensor nodes are randomly deployed and densely in a two-dimensional square field then clustering process begins, then routing and data transmission is done.

Additionally, some assumptions are prepared as follows:

- The network is homogenous with the same characteristics and all of the sensor nodes have the same level of initial energy.
- The sensor nodes are considered to be static in the network and without mobility.
- The communication is symmetric
- Sensor nodes are energy constrained, i.e. non-rechargeable, and always have data to send.
- BS is stationary and has no energy constraint.
- All nodes are supplied with using (GPS) devices; therefore the node is aware of its location and location of the BS.

4.1 Setup phase

The setup phase consists mainly of cluster formation, and CH cluster head selection. After deploying the nodes, the sensor nodes must be divided into clusters. The sensor nodes can know their positions by using GPS devices and then send their location coordinates to base station. By considering the sensor nodes locations and using the Fuzzy C-Mean algorithm of clustering, Clusters of nodes are effectively formed by the base station. The clustering substructure is performed only once at the base station and remains static through all the network lifetime.
The Fuzzy C-Means algorithm divides the network to predefined number of clusters. Every cluster consists of a group of sensor nodes and it is not necessary for the number of nodes to be equal in clusters. In the proposed work, initially the CH is selected in each cluster; the closest node to the cluster center is elected as a CH for the first round because all the nodes have the same amount of energy.

This is performed only at the start, but then, a rotation scheme using Fuzzy Inference System is implemented to select the next cluster heads based on three parameters (residual energy level, the distance to base station and the distance to cluster-head).

Algorithm 1: The Fuzzy C-means algorithm [20]
Input: position of nodes
Output: cluster centers
Begin
  initialize Uf
  repeat
    for cluster j =1 to c **do**
      $cj \leftarrow$ compute cluster centroid
    end for
    update Uf
  until the algorithm converges
  return {C}
End

After that base station broadcasts the selected cluster-heads list to the network, the sensors that are declared as CHs begin to act as CHs and broadcast their existence in the network. Then nodes join to the nearest cluster-head and each CH prepares the TDMA scheduling and broadcasts it to its members.

The following algorithm (2) shows the setup phase for the proposed protocol.

Algorithm 2: Setup phase
Input: N= number of sensor nodes
Output: A set of clusters and selected cluster- heads (CHs)
Start
Step 1: Suppose the network area is of M×M meters
Step 2: Randomly deploy the N sensor nodes in the predefined area.
Step 3: Sensors nodes send their location information to the Base Station.
Step 4: Apply fuzzy c-mean clustering algorithm (FCM) by BS for Cluster-Formation.
Step 5: Find the final clusters centers by the FCM algorithm.
Step 6: Select the closest node to cluster center as cluster-head.
Step 7: calculate the distances and energy to select the cluster-heads for next rounds
Step 8: Base Station broadcasts the cluster-heads list to the WSN
Step 9: Cluster-heads declare themselves as (CHs) by receiving cluster-heads list.
Step 10: Sensor nodes join to the closest cluster-head.
Step 11: Each cluster-head broadcasts TDMA schedule to its members.
End

4.1.1. Cluster Formation

FCM algorithm begins with an initial estimate of the cluster centers, which aims to determine the average position of each cluster. The initial estimate of these cluster centers is probably incorrect. In addition, FCM assigns each sensor node a membership degree to each cluster within range of [0-1]. By frequently updating the clusters centers and the membership degrees for each sensor node using the equation

(1) and (2), Fuzzy c-mean iteratively moves the centers of clusters to the correct location within clusters.

This iteration is based on reducing the objective function which representing the distance from any particular sensor node to the center of cluster weighted by the membership degree of that node.

The iteration of these equations is continued until satisfying the convergent condition. The convergent condition represents the difference between the newly calculated cluster center and the last calculated cluster center, and it should be less than or equals to (0.00001). When that condition is met, the FCM process is terminating,

The algorithm selects the closest nodes to the centers as cluster heads since the cluster center location inside the cluster is the most suitable location to be cluster head. This is because the center of cluster mediates all sensors within the cluster, which in turn decreases the energy amount required by sensor nodes to transmit data. In addition, all the nodes initially have the same amount of energy; therefore, there is no higher priority for node to become a CH unless it is near to the center of cluster. The algorithm (3) shows steps of cluster-formation.

Algorithm 3: Cluster-formation
Input: N= number of sensor nodes of WSN, K= number of desired clusters.
Output: A set of k clusters with centers.
Start
Step 1: Sensors nodes send their location information to the Base Station.
Step 2: Formation the clusters by BS using fuzzy c-mean clustering algorithm (FCM) after determining the number of clusters.
- choose the K number of clusters
- Initialize cluster centers randomly
- t=1

Step 3: calculate new centers for cluster and membership degree for each sensor node in all clusters using the Equation (2) and (3)
- t=t+1

Step 4: moving each center to the mean value of the sensor nodes locations in its cluster.
Step 5: if termination condition is satisfied stop, else go to step 3.
Step 6: After the centers of clusters are found by (FCM), the closest node to cluster center is selected as cluster-head
Step 7: sensor nodes join to the closest cluster-head
End

After selecting the cluster heads, the nodes join to the closest CH by finding the Euclidean Distance of each node to all the elected cluster heads and then assigning the node to the closest cluster.

Hence clusters can be obtained with their CHs which are selected depending on the distance to the centers using FCM algorithm. This is only at in the first round. Then each CH prepares the TDMA scheduling and broadcasts it to its members.

4.2 Steady phase

The data Transmission phase is similar to that in LEACH and it can start after the formation of clusters and the selection of cluster-heads. In the Steady transmission phase, the normal nodes in the clusters transmit the data to the base station but not directly, they transmit it to the cluster-heads according to the TDMA tables; Each node sends to its cluster-head only in its allocated time slot while remains in the sleep mode for the rest of the time to save energy. The CH collects the data received from its members and transmits the aggregated data to the BS after fusing. The CHs use a CSMA/CD for transmission to the BS.

5. Performance Metrics

For evaluating the performance of the proposed algorithm, there are some performance metrics are used to compare and analyze the results in the Wireless Sensor Network. These metrics are: Energy Consumption and Network Lifetime.

Energy consumption is the total amount of energy consumed by all the sensor nodes that form the networks and it represents the difference average between the initial energy level and the current level of remaining energy for each node in each round.

$$E(i)_{consumed} = E(i)_{initial} - E(i)_{remaining}$$

$$E(total)_{consumed} = \sum_{i=1}^{N} E(i)_{consumed}$$

Network Lifetime is measured as the time duration taken from the start of the network configuration till the death of the last sensor node in network. It is represented as a number of rounds made by the nodes. The single round is defined as the process starting from cluster formation until the BS receives the data from CHs.

6. Simulation and Analyze Results

In this section, the proposed algorithm is presented and compared to the LEACH protocol in WSN. System simulation is performed under MATLAB (R2017 b) using a windows 10 OS on an i7 PC, and with the parameters listed in Table 1.

Table 1: The specific parameters in simulation

Parameters	*Value*
Network size	100 m^2
Number of nodes	100
Base Station location	(50,150)
Number of clusters	5
Packet size	4000bit
E_0 =Initial energy	1J
E_{elec}	50nJ/bit
ε_{fs}	10pj/bit/m^2
ε_{mp}	0.0013pj/bit/m^4

E_{DA}	5nJ/bit

100 static sensor nodes are randomly deployed to cover the sensing area. Each node sends a packet of size 4000-bit to the base station via the cluster-head during each round. Figure 2 shows the simulation network of unclustered 100 sensor nodes deployed in 100m x100m WSN.

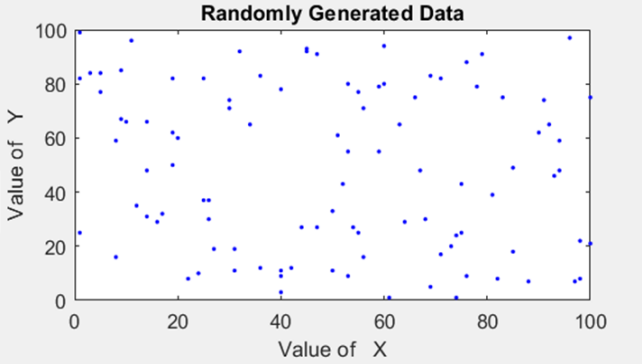

Figure 2: The initial wireless sensor network

Then number of clusters is chosen to be five clusters to distribute the sensor nodes into clusters by applying the FCM clustering algorithm to create more symmetric clusters as shown in figure 3, which illustrates the position of the final centers clusters of clusters.

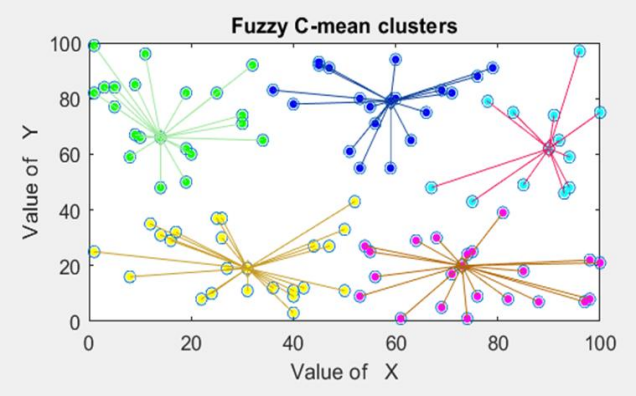

Figure 3: Clustering with the proposed FCM algorithm

Due to the methodology of the solution proposed in this network, a better cluster formation can be obtained and an appropriate CH will be selected in every new round according to the distributing of nodes into clusters by using FCM.
So, the proposed algorithm is more convenient to be used in clustering the sensor network.

6.1. Energy Consumption

The simulation uses the setting parameters stated in the Table 1 to study the behavior of the proposed protocol. Figure 4 illustrates the simulation of energy consumption of all nodes per round for the proposed work comparing with the LEACH protocol. As shown the total energy dissipated in the proposed protocol is better than in the LEACH protocol.

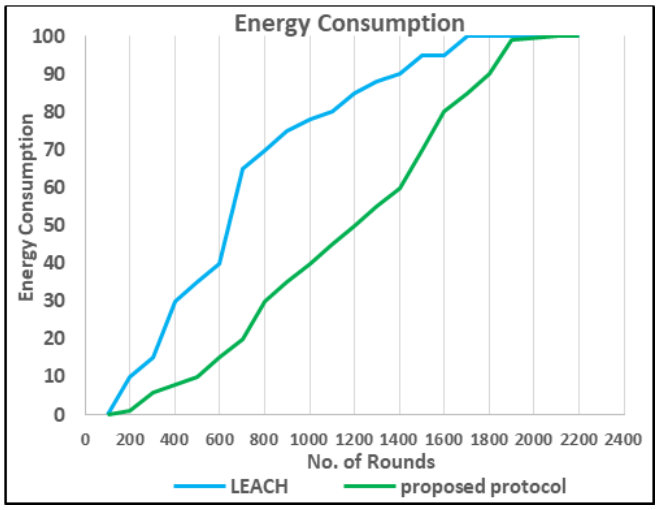

Figure 4: Energy Consumption vs. number of rounds

Using of FCM is resulting in symmetric clusters that reduce the overall transmission distance in each cluster. So the energy consumed in each round is reduced.

6.2. Lifetime of the Network

The Figure 5 shows the number of survival nodes for both algorithms; obviously; the performance of the proposed protocol is clearly better than the performance of LEACH protocol.

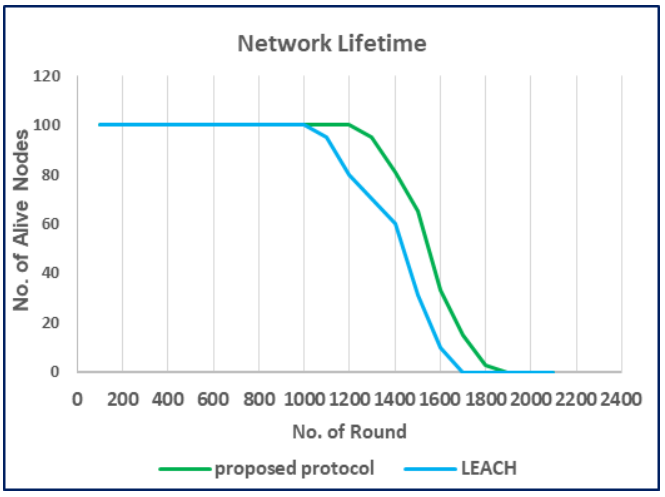

Figure 5: Network Lifetime

Furthermore, to make the result more clearly the FND metric was introduced for both protocols to illustrate the difference. From the below Table 2, the average FND can be determined for 10 runs of LEACH 1121, while in the proposed the average is 1252.

Table 2: FND for proposed protocol and LEACH

Run	*Proposed protocol*	*LEACH Protocol*	Difference
	FND	*FND*	
1	1200	1105	95
2	1255	1100	155
3	1212	1110	102
4	1260	1130	130
5	1266	1145	121
6	1280	1136	144
7	1262	1112	150
8	1260	1140	120

9	1260	1114	146
10	1270	1120	150
Average	1252	1121	131

The use of Fuzzy C-Mean clustering (FCM) reduces transmission distance, thus saving energy and increasing network lifetime. By using this algorithm, clusters have a better formation where the mean distance for each node to the cluster is reduced. It is more effective for balancing network load and distributing nodes between clusters.

7. Conclusions

The main objective of this paper is to design an efficient routing algorithm based on Fuzzy clustering to deal with the issue of energy conservation for WSN. The proposed work uses the FCM clustering algorithm for clusters formation to produce a highly uniform clustering of nodes by reducing the spatial distance for the intra-cluster communications. Forming symmetric clusters by applying fuzzy C-Means cause reduction in energy consumption of sensor nodes which results in extending the WSN's lifetime and also, improves the FND time and LND time of the proposed solution. The simulation results show that the proposal performs better compared with LEACH in terms of energy consumption and extending network lifetime. In the future, the proposed work should be developed and improved to support applications that require event detection using mobile nodes and flexible BS.

References

[1] Alwadi, Mohammad Abdulaziz. "Energy efficient wireless sensor networks based on machine learning." PhD diss., University of Canberra, Australia, 2015.

[2] J. S. Pan, S. C. Chu, T. K. Dao, and V. C. Do. "Improved Performance of Wireless Sensor Network Based on Fuzzy Logic for Clustering Scheme." In International Conference on Smart Vehicular Technology, Transportation, Communication and Applications, Springer, pp. 104-113, Cham, 2019.

[3] Joshi, Akhila, Saurabh Mehta, and Ajitkumar Khachane. "Performance Analysis and Comparison of Cluster Based Routing Protocol in in WSN." IJCST International Journal of Computer Science Trends and Technology, 2347-8578 (2017).

[4] Oudani, Hassan, Salahddine Krit, Mustapha Kabrane, Kaoutar Bandaoud, Mohamed Elaskri, Khaoula Karimi, Hicham Elbousty, and Lahoucine Elmaimouni. "Energy efficient in wireless sensor networks using cluster-based approach routing." International Journal of Sensors and Sensor Networks 5, no. 5-1 (2017): 6-12.

[5] Eshaftri, Mohamed, and Mr Mohamed Eshaftri. "Adaptive energy management mechanisms for cluster based routing wireless sensor networks." PhD diss., Edinburgh Napier University, 2017.

[6] Vanitha, R., and B. Murali. "Enhancing the life time of wireless sensor network using P-LEACH protocol" International Journal of Computer Science and Mobile Computing IJCSMC, Vol. 6, Issue. 9, pg.8 – 14 : 2320–088X , (September 2017).

[7] Wang, Quyuan, Songtao Guo, Jianji Hu, and Yuanyuan Yang. "Spectral partitioning and fuzzy C-means based clustering algorithm for big data wireless sensor networks." EURASIP Journal on Wireless Communications and Networking 2018, no. 1 (2018): 54.

[8] Saxena, Shubham, and Anjana Nigam. "Energy Efficient Cluster-Based Routing Protocol over Wireless Sensor Network." International Journal of Computer Security & Source Code Analysis (IJCSSCA), Vol3, Issue2, ISSN (O): 2454-5651, 2017.

[9] Wang, Shaoqing, Jiguo Yu, Mohammed Atiquzzaman, Honglong Chen, and Lina Ni. "CRPD: a novel clustering routing protocol for dynamic wireless sensor networks." Personal and Ubiquitous Computing 22, no. 3 (2018): 545-559.

[10] Anitha, G., V. Vijayakumari, and S. Thangavelu. "A Comprehensive Study and Analysis of LEACH and HEED Routing Protocols for Wireless Sensor Networks–with Suggestion for Improvements." Indonesian Journal of Electrical Engineering and Computer Science 9, no. 3 (2018): 778-783.

[11] Soumya Ranjan Mohanty, S., R. and B.Pranja "Study and implementation of fuzzy c-mean clustering algorithm in wireless sensor network" International Journal of Computer Application (2250-1797) Issue 8 Volume 1, January- February 2018.

[12] Chelbi, Slaheddine, Majed Abdouli, Mourad Kaddes, Claude Duvallet, and Rafik Bouaziz. "An Unequal Cluster-based Routing Protocol Based on Data Controlling for Wireless Sensor Network." International Journal of Electrical and Computer Engineering 6, no. 5 (2016): 2403.

[13] Hosen, A. S. M. S., and Gi Cho. "An energy centric cluster-based routing protocol for wireless sensor networks." Sensors18, no. 5 (2018): 1520.

[14] Dehghani, Shahrzad, Behrang Barekatain, and Mohammad Pourzaferani. "An Enhanced Energy-Aware Cluster-Based Routing Algorithm in wireless sensor networks" wireless personal communication 98, no. 1(2018):1605-1635.

[15] An, Lei, Aihua Li, Ling Pang, and Guangdong He. "Analysis and Comparison of Routing Protocol of Wireless Sensor Network." International Journal of Online Engineering (iJOE)12, no. 10 (2016): 4-10.

[16] Tamandani, Yahya Kord, Mohammad Ubaidullah Bokhari, and Qahtan Makki. "A comparative study of various routing classes and their key goals in wireless sensor networks." In Next-Generation Networks, pp. 271-279. Springer, Singapore, 2018.

[17] Barzegari, Smira, and Mohammad Masdari. "A novel fuzzy CMeans-based clustering scheme for wireless sensor networks." International Journal of Grid and Distributed Computing 9, no. 2 (2016): 193-202.

[18] Kaushik, Amit Kumar. "A hybrid approach of fuzzy c-means clustering and neural network to make energy-efficient heterogeneous wireless sensor network." International Journal of Electrical and Computer Engineering 6, no. 2 (2016): 674.

[19] Mahboub, Aziz, Mounir Arioua, and Hamid Barkouk. "Fuzzy C-Means Based Hierarchical Routing Approach for Homogenous WSN." In Proceedings of the

Mediterranean Symposium on Smart City Applications, pp. 265-275. Springer, Cham, 2017.

[20] Tamene, Melaku, Kuda Nageswara Rao." Fuzzy C-Means Clustering Algorithm for Optimization of Routing Protocol in Wireless Sensor Networks." IJCSN International Journal of Computer Science and Network, 2277-5420 (2016).

[21] Huang, Wenwei, Yun Ling, and Weilong Zhou. "An Improved LEACH Routing Algorithm for Wireless Sensor Network." International Journal of Wireless Information Networks 25, no. 3 (2018): 323-331.