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Energy Efficient Fuzzy C-Means and RED_LEACH Based Clustering Algorithm in Wireless Sensor Networks

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***Abstract*— The main issue in Wireless Sensor Networks (WSNs) is its lifetime which impacts on various real time applications. One of the leading techniques to increase the lifetime of WSN is dividing the WSN's nodes into clusters (Clustering). It includes two phases: clusters formation phase and cluster head (CH) selection phase. This paper contributes a hybrid clustering algorithm that combines Fuzzy C-Means (FCM) clustering and RED_LEACH Protocol (Lifetime Improvement of Wireless Sensor Network using Residual Energy and Distance Parameters on LEACH Protocol) features. Fuzzy C-Means clustering is used to make similar sized and optimal clusters at cluster formation phase and RED_LEACH protocol is used to decide the right cluster head (CH) using the parameters: residual energy of each node and distance to base station (BS) which extend the lifetime of the WSN. The proposed clustering algorithm is simulated using Matlab in different scenarios, rounds and number of nodes and its results are compared with the results of LEACH protocol and RED_LEACH protocol in term of sum of energy of nodes against rounds and the number of dead nodes against rounds. The simulation results clearly prove that the lifetime of WSNs is increased by this proposed clustering algorithm over LEACH and RED_LEACH.**

Keywords— Wireless Sensor Networks (WSNs), cluster formation, cluster head selection, Fuzzy C-Means, LEACH, RED_LEACH

I. Introduction

Wireless sensor networks (WSNs) have been widely used as a standard information gathering tool in a wide range of applications, such as environmental monitoring, industrial applications, target tracking, battlefield surveillance, home security, precision agriculture, animal tracking and health monitoring. Sensor nodes with limited resources in terms of energy, memory, and computation are connected together to form a WSN. Each sensor node is employed with a small battery. This battery can store some amount of initial energy, and a fraction of it is consumed in every communication. During the network lifetime, many communications are taken place and the battery will be exhausted due to these communications. When WSNs are placed in harsh environment or in a kind of environments where it is difficult to reach, in most of the cases there is no way to recharge these batteries. This is the fact that minimizing energy consumption when designing the routing protocol is very important to increase the lifetime of WSNs.

Clustering protocols are the best solution for decreasing the energy use in WSNs. By using these protocols, the nodes in WSNs are divided into clusters and each node has their role such as cluster head (CH) and cluster members. The cluster head node collects data from all other cluster members and forwards these data to the base station (BS). Cluster head (CH) uses more energy than other member nodes in their cluster and the life of the network depends on that CH. So, the duty of cluster head (CH) must be assigned in rotational manner to share energy consumption and to design the protocols that can balance energy consumption.

This paper is composed of seven sections. Section II presents review on protocols and Section III presents radio energy dissipation model. Section IV and V presents the process of FCM and RED-LEACH protocol respectively. In section VI, the detail of proposed algorithm is presented and simulation results and analysis are shown in section VII. Finally, section VIII concludes this paper.

II. Related Works

There are many protocols to extend the lifetime of WSNs and the most famous is Low Energy Adaptive Clustering Hierarchy Protocol (LEACH) that was proposed by Heinzelman et.al [1]. In LEACH, cluster head selection is based on randomized probability without considering the residual energy and proximity to the BS of that node. On the basis of LEACH protocol LEACH-C [2] was proposed, in which the formation of clusters is performed using centralized algorithm by the base station (BS). It solved the problem of LEACH by electing cluster head (CH) on the basis of residual energy and distance from BS. The overall performance of LEACH-C is better than LEACH but it is sensitive to BS location. Ahlawat et.al [5] proposed a protocol, vice-CH LEACH (V-LEACH) to avoid base station overhead by considering the second CH. It uses the minimum distance and maximum residual energy to extend the network lifetime and the vice-CH acts as CH when a main CH fails. V-LEACH gives satisfactory performance than LEACH and LEACH-C. However, VLEACH itself faces the extra overhead for choosing the vice-CH because it chooses vice-CH whenever it is necessary or not. A hybrid

algorithm called LEACH-VF [7] proposed by Wang et.al, uses two types of virtual forces: attractive and repulsive force. This algorithm reduces energy for communication by using attractive force and eliminates cluster overlapping by using repulsive force and thus it can maximize the coverage area. This algorithm still has the weakness of low energy efficiency and non-uniform distribution of energy among nodes. Khedri et.al [8] developed a new energy efficient algorithm called OLEACH. In this algorithm, a node is selected as cluster head if it has the energy greater than 10% of the initial energy but other influential parameters such as distance are not considered.

Bouyer et.al [12] created optimum number of CHs in LEACH algorithm by using Fuzzy C-Means (FCM) algorithm to reduce energy and to prolong the network lifetime. In this hybrid algorithm, each node compares its status based on three basic characteristic of energy, distribution and the center localization with the status of the other nodes in the neighbor nodes and if the energy of it is more than the neighbor node, introduces itself as the CH node and then the clustering starts by joining the nodes to the nearest cluster. Alami et.al [13] created the protocol named CAFL, in which the residual energy and closeness to base station value of each node are used to compute the chance value during CHs selection process. The sensor node which has the highest chance value will become CH for the current round. After selecting CHs, they send advertisement message over sensors network to inform remaining sensor nodes that it is the CH and the cluster formation task is done. Therefore, energy consumption is decreased in network which means the lifetime of WSNs is maximized.

All research works have their idea and solutions for improving the network lifetime of WSNs. But there could have many other approach for increasing WSNs' lifetime and the proposed hybrid protocol that combined Fuzzy C-Means and RED_LEACH is unique in its own method, in which cluster heads (CHs) are elected based on both node's residual energy and closeness to base station (BS). The detailed process of the proposed protocol is explained in further section.

III. Radio Energy Dissipation Model

The first order radio model [2] can be divided into two propagation models such as free space propagation model and two-ray ground propagation model according to the distance between the transmitting sensor node and the receiving sensor node as shown in Fig. 1. The free space propagation model supposes there is no effect of the earth surface reflection and absorbing obstacles between the transmitter and the receiver. The two-ray ground propagation model considers both the direct path and a ground reflection path that means the transmitter and the receiver is not direct and the electromagnetic waves will bounce off the ground and arrive at the receiver from different path at different instant of time.

The energy dissipation of m-bit message between two sensor nodes (transmitter and receiver) with the distance d is defined as:

$$E_{TX}(m,d) = \begin{cases} m \times E_{elec} \times m \times \varepsilon_{fs} \times d^2, & \text{if } d \le d_0 \\ m \times E_{elec} \times m \times \varepsilon_{mp} \times d^4, & \text{if } d > d_0 \end{cases} \quad (1)$$

where E_{TX} (m,d) is the energy dissipation in transmitting m-bits packet with a distance d, and E_{elec} is the energy dissipation per bit to run the transceiver circuit. The parameters ε_{fs} and ε_{mp} are the amplifier parameters for the free space propagation model and the two-ray ground propagation model respectively. The threshold distance d0 between two-ray ground propagation model and free space propagation model can be obtained from:

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \quad (2)$$

If the distance between the transmitter and the receiver is larger than the threshold distance, the two-ray ground model is used. Otherwise, the free space model is considered to measure the energy dissipation. Energy required for receiving m-bits message is

$$E_{RX}(m) = m \times E_{elec} \quad (3)$$

IV. Fuzzy C-Means Clustering

FCM first proposed by Bezdek [6] is a centralized clustering method in which the base station have to compute and allocate sensor nodes into clusters according to the their location. Consider a network of i sensor nodes which is partitioned into j clusters: C1, C2, ..., Cc. The purpose of the cluster formation in this protocol is to minimize the following objective function:

$$J_m = \sum_{i=1}^{N} \sum_{j=1}^{c} u_{ij}^m \| x_i - c_j \|^2 \quad (4)$$

where the value of m must be greater than 1, u_{ij} is the membership degree of x_i belonging to cluster j and x_i is the i_{th} node, c_j is the center of the j_{th} cluster. Fuzzy C-Means clustering is carried out by updating the above objective function in iterative manner. The membership uij and the cluster centers cj is updated by the following equation:

$$u_{ij} = \frac{1}{\sum_{k=1}^{c} \left(\frac{\| x_i - c_j \|}{\| x_i - c_k \|} \right)^{\frac{2}{m-1}}} \quad (5)$$

$$c_j = \frac{\sum_{i=1}^{N} u_{ij}^m . x_i}{\sum_{i=1}^{N} u_{ij}^m} \quad (6)$$

V. RED-LEACH Protocol

Similar to LEACH protocol, the RED-LEACH protocol [14] operates in rounds, each divided into set-up (cluster formation) phase and steady state (data transmission) phase. The main difference between RED-LEACH and LEACH protocol lies in the cluster head selection stage. LEACH protocol uses random numbers to select CHs and it uses "(7)" to compute threshold value, and thus it suffers from drawbacks such as non-uniform distribution of CHs and possibility of electing a node with low residual energy as CH that leads to decrease the network lifetime.

But in RED-LEACH, it considers the nodes' residual energy and distance to base station that are important in energy efficiency. The node chooses the random numbers between 0 and 1 to select CHs. To become a cluster head (CH), each node must have the shorter distance to base station (BS) than the mean value of all distance and its random number must be less than the following threshold:

$$T(n) = \begin{cases} \dfrac{P}{1-P\times(r\times \mathrm{mod}(\frac{1}{P}))} \times E_r(i), if n \in G \\ 0, otherwise \end{cases} \quad (7)$$

where r is the current round number, P is the desired percentage of cluster head (CH) in the round, and n is the number of nodes in the area network. G is the set of nodes that have not become cluster head (CH) in the last 1/P rounds and $E_r(i)$ is the residual energy of each node. LEACH protocol does not consider the node's residual energy, RED_LEACH calculates the threshold value by multiplying the node's current residual energy to reduce dead nodes in order to extend the network lifetime. If a node that can satisfy the above requirements, it becomes CH for this round. The CH broadcasts advertisement message to all nodes and the network indicating that it has CH node and invites other nodes to join it and forms a cluster.

VI. Proposed Algorithm

In this research work, WSNs have N numbers of sensor nodes and they are uniformly distributed over the M*M bounded area in order to continuously monitor the environment. The collected data from each sensor node is transmitted to the base station (BS) through CHs. Concerning the WSNs environment, some assumptions need to be defined as follows:

- All the nodes are homogeneous in nature (that is identical sensing and communication capabilities and the same energy resources).
- All the nodes are immobile for their lifetime.
- The base station (BS) is located at the center of the bounded area and it is also immobile.
- The consumed energy for data transmission from the transmitter to the receiver is the same that of transmission from receiver to the transmitter.

The proposed clustering protocol includes three phases: clustering formation, cluster head selection and data transmission. FCM clustering protocol is firstly applied in cluster formation stage to cluster the sensor nodes. The issue of LEACH protocol in cluster formation stage is that the distribution of clusters is not uniform (that is, there are many clusters some of which contain a large number of nodes take place in large network area but the others have a few nodes). The consequences of the above issue of LEACH is that the CH of one cluster with large number of nodes has to experience heavy data transmission traffic which causes more power consumption at CH and waste energy because of data collision. Moreover, many sensor nodes that are located far away from the CH have to use more energy to transmit data from these nodes to CHs over longer distance. In this proposed protocol, by using FCM in cluster formation stage, the above-mentioned issue of LEACH in cluster formation is resolved. According to FCM protocol, each node is assigned a degree of belonging to cluster i rather than completely being a member of just one cluster. Therefore, the nodes close to the boundary of a cluster may become members of the cluster with a degree approximating the degree of belonging to the neighbor clusters and thus mean distance from each node to the cluster is minimized. It is more efficient to balance the load of network and to distribute the nodes among clusters by using FCM.

The operation of the proposed protocol is divided into rounds. In each round, the cluster head (CH) in each cluster collects data from all cluster members and transfer that data to the BS, so the cluster head (CH) that represents for each cluster is selected first. In LEACH protocol, the CH selection is made without considering the node's residual energy and distance to the base station, thus the node with least residual energy can be cluster head (CH) and the network will expire so early. Moreover, there may be more than one cluster head (CH) for each cluster and the node that is not proximity to BS can become CH that can cause more energy dissipation according to the energy dissipation model in (WSNs). By combining the RED-LEACH protocol, the proposed protocol considers the node's residual energy as well as distance to the center of cluster instead of distance to base station (BS) used in RED-LEACH while choosing CHs so that the node with highest residual energy and nearest to the cluster center to be a cluster head (CH). By using the distance to cluster center parameter while choosing CHs, the distance between CH and cluster member nodes can reduce and more energy can save than using the distance to base station parameter. The process of choosing the cluster heads (CHs) is repeated every round.

After choosing the CHs, data transmission phase is performed, all sensor nodes in each cluster start to transmit data to their respective CHs. The CH nodes make data aggregation and then sent them to the base station (BS). The power consumption to transmit data from non-cluster head nodes to CH is reduced by using the RED-LEACH protocol.

VII. Simulation Setup And Result Analysis

The proposed FCM and RED_LEACH hybrid protocol is implemented using the MATLAB programming language and the performance of this hybrid protocol is analysed and compared with LEACH protocol and RED-LEACH protocol using two performance metrics such as sum of energy of nodes against round and the number of dead nodes against round. In simulation, 100 nodes each containing energy of 0.5 Joules are distributed in 100m*100m sensing area. The detail of simulation parameters are specified in Table 1.

TABLE I. Parameters Setup For Simulation

Parameters	Value
Initial Energy E0	0.5 J
Electronic Energy Eelec	50nJ/bit
Free Space Model Efs	10pJ/bit/m2
Multipath Model Emp	0.0013pJ/bit/m4
Data Aggregation Energy EDA	5nJ/bit/signal
No. of node	100
No. of round	3000

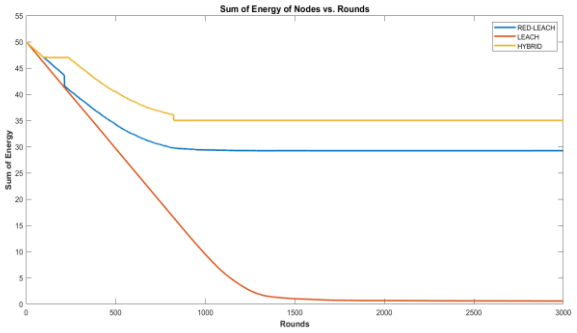

Fig. 1. Comparison of energy consumption over 3000 rounds

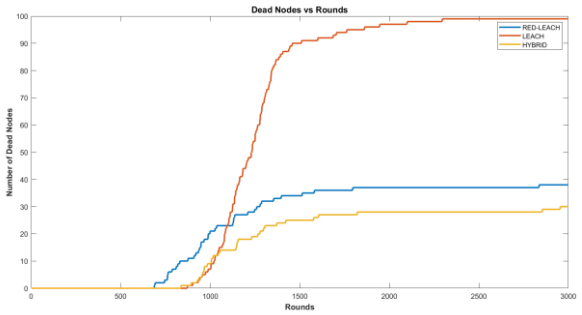

Fig. 2. Comparison of dead nodes over 3000 rounds

Comparison of proposed hybrid protocol with LEACH and RED-LEACH protocol to observe the dissipation of energy of nodes in each round is presented in Fig. 2 for 3000 rounds. The hybrid protocol can save more energy than LEACH and RED-LEACH. Sum of energy of the whole network is rapidly decrease in LEACH but the better stability value can maintain in RED_LEACH and the proposed hybrid protocol. But the proposed hybrid protocol outperforms the two other protocols. It can maintain the total energy value to 35 Joules until 3000 rounds where RED-LEACH can maintain 29 Joule. But in LEACH protocol the value drops below 1 Joules after 2000 rounds. According to the results, the proposed hybrid protocol saves energy more than LEACH and RED_LEACH because of the uniform distribution of nodes in each cluster and the method for choosing cluster head (CH) using residual energy and closeness to the cluster center.

Fig. 2 represents the dead nodes comparison of three protocols over 3000 rounds. The proposed hybrid protocol and RED_LEACH protocol able to keep more alive nodes longer time compared to LEACH protocol. If comparison is made for first node die of LEACH and proposed hybrid protocol, both the two protocol can perform almost the same where RED_LEACH faces the first node die at round number 600. After 3000 rounds, nearly all the nodes die using LEACH protocol but still exist many nodes in the networks that use the proposed hybrid protocol and RED-LEACH protocol but the proposed hybrid protocol is better. is more suitable for wireless sensor network than LEACH protocol. The simulation results prove that the hybrid protocol offers a remarkable performance improvement over lifetime of WSNs by reducing energy usage, compared to LEACH and RED-LEACH protocols.

VIII. Conclusion

This paper presents the hybrid FCM and RED-LEACH protocol in order to reduce energy consumption and to prolong the lifetime of WSNs. According to the simulation results, the lifetime of WSNs can be extended by using this hybrid protocol. Moreover, this protocol is more powerful than LEACH protocol and RED-LEACH protocol.

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