FCM-SEP (Fuzzy C-Means Based Stable Election Protocol) for Energy Efficiency in Wireless Sensor Networks

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Abstract – Sensor networks are widely used networks in the recent times. These networks are generally known as WSN (Wireless Sensor Networks). These became popular because of the advancements in the micro-electro mechanical systems and their wide application areas. These work in hard-to-reach locations. These have limited batteries as well as limited computational capabilities available with them. So battery conservation is very necessary in these networks so that their lifetime can be enhanced. There are various routing protocols used for energy efficiency of the network. Homogeneous and Heterogeneous are two network schemes in WSN. Out of these two, heterogeneous protocols are more energy efficient than the homogeneous protocols. SEP (Stable Election Protocol) is one of the heterogeneous protocols in WSN. It increases the stability period of the network. In the proposed work, Fuzzy C-Means Clustering is used in SEP Protocol in order to make the network more energy efficient. Simulation result shows that FCM-SEP (Fuzzy C- Means based Stable Election Protocol) shows better performance than SEP Protocol.

Index Terms – Wireless Sensor Network; Routing; FCM; SEP

1. INTRODUCTION

WSN is composed of large number of tiny, low cost and low power sensor nodes commonly used for monitoring the environmental conditions such as Sound, Vibration, Pressure, Temperature, Humidity and many other similar conditions [1-5]. These sensor nodes continuously send this sensed information to the special node which is known as Base Station (BS) or Sink. Base Station collects all the data from nodes and after necessary processing, it passes the whole data to the internet from where it is accessible to the end users. These nodes communicate each other using Radio Signals.

These networks become very popular because of their wide application areas such as Disaster surveillance, Military field, Agriculture, Health Monitoring, Biodiversity Mapping, Intelligent buildings and many other applications.

Wireless Sensor Network poses a great number of challenges as described in [6] in order to obtain its optimal performance like Hardware constraints, power consumption, deployment, scalability, flexibility, network lifetime etc. Energy Consumption becomes the biggest issue in Wireless Sensor Networks. So, the main objective is to reduce the energy consumption so that the network lifetime can be increased. In data transmission, data sensing and communication are the two more energy consuming processes than data processing. So, energy conserving techniques are required to save the energy of the network and to prolong its lifetime.

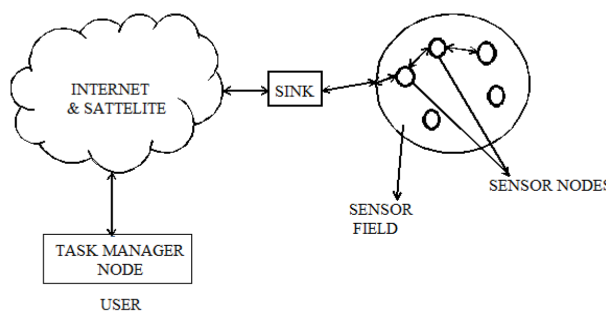

Figure 1 Architecture of Wireless sensor Network [7]

Routing protocols are designed in order to save the energy of the network that result into efficient data transmission and various routing challenges are also handled with them. The Routing Protocols are classified into three main protocols: Flat or data centric routing Protocols, Hierarchical Routing Protocols and Location based Routing Protocols. Among all the routing protocols, Hierarchical routing protocols are considered as the best among other routing protocols.

The hierarchical routing protocols involve cluster-based organization of the sensor nodes in order to save energy of the network. In the hierarchical network structure, every cluster has a leader node which is also called as Cluster Head (CH). It consists of several common sensor nodes as members and it usually performs the special tasks of data fusion and data aggregation.

Hierarchical Protocols are of two types:

A. Homogeneous Routing Protocols

B. Heterogeneous Routing Protocols

A. Homogeneous Routing protocols:

In homogeneous networks, all the nodes of the network are same in terms of hardware complexity and battery. These networks have completely static clustering involved with them. These networks are not complex in nature and single network topology is used in them. Thus, the sensor networks in which the nodes have identical battery energy and other parameters are known as homogenous sensor networks. Commonly used Homogeneous Routing Protocols are LEACH (Low Energy Adaptive Clustering Hierarchical Routing Protocol), TEEN (Threshold sensitive Energy Efficient sensor Network protocol), HEED (Hybrid Energy Efficient Clustering Protocol), PEGASIS (Power-Efficient GAthering in Sensor Information Systems), APTEEN (Adaptive Periodic Threshold-sensitive Energy Efficient Sensor Network Protocol), etc [8].

B. Heterogeneous Routing Protocols:

In heterogeneous networks all the sensor nodes have different battery powers and different functionalities. These networks have different topologies which make them a very complex in nature. Hence, in case of heterogeneous sensor networks, there are two or various types of network nodes having different energies and functionalities.

The Common Heterogeneous Routing protocols are SEP(Stable Election protocol), DEEC (Distributed Energy Efficient Clustering Protocol), EDEEC (Enhanced Distributed Energy Efficient Clustering Protocol) etc [8].

2. RELATED WORK

LEACH is one of the homogeneous protocols used for energy efficiency in Wireless Sensor Networks. Malik M. *et al*. [9] described the LEACH protocol is a basically a representation of hierarchical routing protocol. It is a self-organized and self-adaptive in nature. It uses round as units where each round is made up of cluster set-up state and steady state. The steady-state phase is normally longer than set-up phase. However, the set-up phase is more important in which sensor nodes elect themselves as cluster-heads in a random fashion and then grouped into clusters. Each node which becomes the cluster head (CH) will create a TDMA schedule for the other members of the cluster. TDMA is essential as it allows each non-CH node to turn off their radio components all the time except during their transmission time.

Smaragdak G. *et al.* [10] have proposed a SEP protocol in order to prolong the stable region and it also SEP maintains the constraint of well-balanced energy consumption. It is heterogeneous in nature and advanced nodes have to become cluster heads more often than the normal nodes. It helps in fair energy distribution in the network. Karthikeyan A. *et al.* [11] described that the clustering is of two types i.e., hard clustering and soft clustering. Hard clustering involves a data element that can be a member of only one cluster. But in soft clustering, data element is a member of more than one cluster, and each element is associated with a set of membership levels. Fuzzy C Means (FCM) Algorithm is one of the commonly used fuzzy clustering algorithms. In this paper, all the simulation results demonstrate that the fuzzy logic based CH selection reduces the rate of energy consumption and LEACH-F is able to operate more number of rounds. As a result, this new method of cluster head selection has an advantage of energy efficiency when compared with the LEACH protocol. Bezdek J. C. *et al.* [12] have described the FCM which is the fuzzy C-Means clustering. It is the well-known method of clustering. In this algorithm, the main aim is to optimize the objective function. Every data of the set belongs to more than one cluster with their memberships in every cluster. The membership value close to unity have high degree of similarity between sample and cluster whereas the membership value close to zero shows the less similarity between the sample and cluster. Dutta R. *et al.* [13] have proposed a new protocol named as low energy adaptive unequal clustering protocol based on Fuzzy c-means clustering (LAUCF). It is a model relying on unequal clustering size model used for the organization of sensor network. It is basically based on Fuzzy c-means (FCM) clustering algorithm. This method leads to more uniform energy dissipation among the cluster head nodes as a result of which network lifetime has been increased. It has been demonstrated in this paper that the throughput of the system is better by this protocol when compared with TEEN, SEP and LEACH. LAUCF has better data transfer rate than TEEN, SEP, LEACH-C and LEACH. On comparing LAUCF with LEACH, it has been found that LAUCF has better performance than other protocols. So it has been concluded from the related work that the network can be made more energy efficient on implementing the fuzzy based clustering.

3. PROPOSED WORK

In this work, Fuzzy C-Means Clustering is used in the SEP Protocol. The clusters are formed with the help of Fuzzy C-Means method. It is one of the fuzzy based clustering methods. In this algorithm, the main aim is to optimize the objective function which minimizes intra-cluster variance. Every data of the set belongs to more than one cluster with their memberships in every cluster. This objective function tends to minimize the distance between cluster head and base station that helps to reduce the energy consumption to transfer the aggregated data from each cluster head to the base station. The objective function is calculated by the expression:

$$Jm = \sum_{k=1}^{n}\sum_{i=1}^{c}[\mu Ai(Xk)]^{m}.\parallel Xk - Vi \parallel \hat{}2$$

where J_m is the squared error for fuzzy clusters set which is represented by the membership matrix μ and by the set of cluster centres i.e., V. $\|x_k - v_i\|^2$ represents the distance between the sample of the data set say x_k and the cluster centre, say v_i.

The steps of Fuzzy C-means Clustering Algorithm are as:

Step 1: Choose the number of Clusters,

Step 2: Assign initial centroids to the clusters. These centroids are assigned on a random basis.

Step 3: Compute the distance between the data sample of the set and Cluster Centroid of the cluster.

Step 4: Based on this distance, re-compute the membership functions.

$$Vi = \frac{\sum_{k=1}^{n}[\mu Ai(Xk)]\hat{}m\,.Xk}{\sum_{k=1}^{n}[\mu Ai(Xk)]\hat{}m}$$

Where μ is the membership function, m ia a real number influencing the grade of membership.

Step 5: After the computations of membership functions, centroids are re-computed.

Step 6: If the distance between original centroid and next Centroid is less than the threshold value (let say ε), then algorithm stops, else repeat the steps.

So, the clusters are formed on the basis of FCM algorithms. After cluster formation, the cluster heads are selected based on the probability and threshold values of SEP protocol.

Selection of Cluster Head is based on SEP in FCM-SEP protocol:

SEP is a heterogeneous protocol in which a percentage of the sensor nodes are equipped with additional energy which is the source of heterogeneity. It may result from the initial setting of the network or as the network evolves. SEP is a heterogeneous-aware protocol which is basically used to prolong the time interval before the death of the first node which is also referred to as stability period.

SEP improves the stable region of the clustering hierarchy process using the characteristic parameters of heterogeneity. There is a fraction of nodes having more energy than the normal nodes which are referred to as the advanced nodes. To prolong the stable region, SEP attempts to maintain well-balanced energy consumption constraints.

For energy conservation purpose, advanced nodes have to become cluster heads more often than the normal nodes. This is done for fairness in energy consumption. Value of optimal probability, Popt does not change as the new heterogeneous setting does not affect the spatial density of the network but the total energy of the system changes. Let Eo is the initial energy of each sensor node. The energy of each advanced node is $Eo.(1+\alpha)$ Where α is the additional energy given to the advanced nodes, the fraction of advance nodes is represented by m and n is the total number of nodes. So, the total energy of the heterogeneous network is equal to:

$$n.(1-m).Eo + n.m.Eo.(1+\alpha) = n.Eo.(1+\alpha.m)$$

Hence, the total energy of the network is increased by a factor of $1+\alpha.m$

In the heterogeneous network, the average number of cluster heads per round per epoch is

$$n.(1+\alpha.m) \times Pnrm$$

The weighed election probabilities for normal and advanced nodes are given as:

$$Pnrm = \frac{Popt}{(1+\alpha.m)}$$

$$Padv = \frac{Popt(1+\alpha)}{(1+\alpha.m)}$$

$T(Srnm)$is the threshold for normal nodes, and $T(Sadv)$ is the threshold for advanced nodes.

Thus,

$$\mathrm{T}(Snrm) = \begin{cases} \dfrac{\mathrm{P}nrm}{1-\mathrm{P}nrm.(\mathrm{r} \bmod \frac{1}{\mathrm{P}nrm})} & \text{if Snrm} \in \mathrm{G}' \\ 0 & \text{Otherwise} \end{cases}$$

where *G'* is the set of normal nodes. These have not become cluster heads in the last $1/Pnrm$ rounds. And $T(Sadv)$

$$\mathrm{T}(Sadv) = \begin{cases} \dfrac{\mathrm{P}adv}{1-\mathrm{P}adv.(\mathrm{r} \bmod \frac{1}{\mathrm{P}adv})} & \text{if Sadv} \in \mathrm{G}'' \\ 0 & \text{Otherwise} \end{cases}$$

where *G"* is the set of advanced nodes. These are the nodes which have not become cluster heads in the last $1/Padv$ rounds. Thus, total number of cluster heads per round per epoch is equal to:

$$n.(1-m) \times Pnrm + n.m \times Padv = n \times Popt$$

$n \times Popt$ is the required number of cluster heads per round per epoch. Thus, SEP is a heterogeneous two-level hierarchical network in which a node elects itself as a cluster head based on initial energy of the node relative to that of other nodes.

4. SIMULATION RESULTS

For evaluating the network performance, the simulation is conducted using MATLAB (R2013a).Fuzzy C-Means based Stable Election Protocol (FCM-SEP) is compared with the SEP Protocol. Performance metrics used to compare the results are Number of Alive nodes, Number of dead nodes and Total Remaining Energy of the nodes.

S.No	Simulation Parameters	Values
1.	Network Size	100m×100m
2.	Number of Nodes	100
3.	Location of BS	(50,50)
4.	Packet Size	4000 bits
5.	Initial Energy(E0)	0.5 J
6.	Popt	0.1
7.	Eelec (Transmitter/Receiver electronics)	50 nJ/bit
8.	Efs (Transmit amplifier for Free Space)	10 pJ/bit/t²
9.	Emp (Transmit amplifier for Multi-path)	0.0013 pJ/bit/t^4
10.	EDA (Data Aggregation)	5 nJ/bit

Table 1 Simulation Parameters

4.1 Number of Alive Nodes:

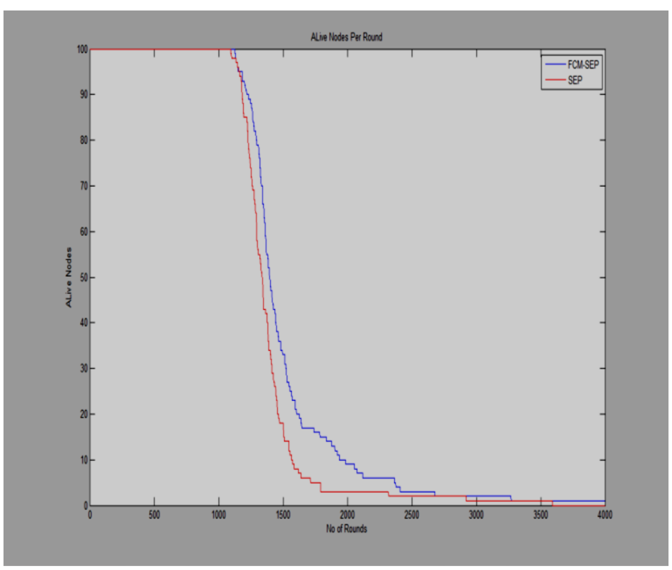

Figure 2 Alive nodes

Number of alive nodes show the network lifetime. Figure 2 shows the no. of alive nodes of FCM-SEP and SEP protocol. Fuzzy SEP is better than SEP protocol as total energy of the nodes is not consumed properly. For some initial rounds SEP performs better as it has more number of alive nodes than FCM-SEP. But after some rounds, FCM-SEP has more number of alive nodes and hence it has a better network lifetime than SEP protocol.

It has shown from the simulation results that FCM-SEP has more number of alive nodes than SEP protocol. FCM-SEP has 9.3% improvement in no. of alive nodes over SEP protocol.

4.2. Number of Dead Nodes:

Number of dead nodes must be less for efficient network. Figure 3 shows the dead nodes of FCM-SEP and SEP Protocol. Dead nodes are those which have consumed their total initial energy. So, It can be noticed from the simulation results that Fuzzy based SEP has the less number of dead nodes than the SEP Protocol. So, FCM-SEP is the better energy efficient protocol than the SEP protocol and hence it has better network lifetime.

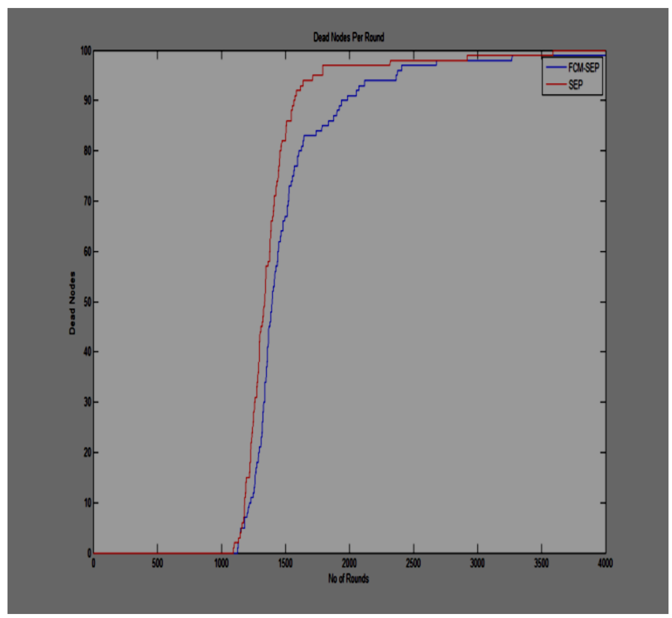

Figure 3 Dead Nodes

4.3 Remaining Energy:

Remaining energy is a very important factor to be studied. More remaining energy leads to better network. Figure 4 shows the comparison of both protocols in terms of remaining energy. Some Initial energy is given to the sensor nodes in the network. But as the simulation is performed, the sensor nodes send the data to the base station and hence their energy is consumed. It is shown in the Simulation results that FCM-SEP has more remaining energy than SEP protocol.

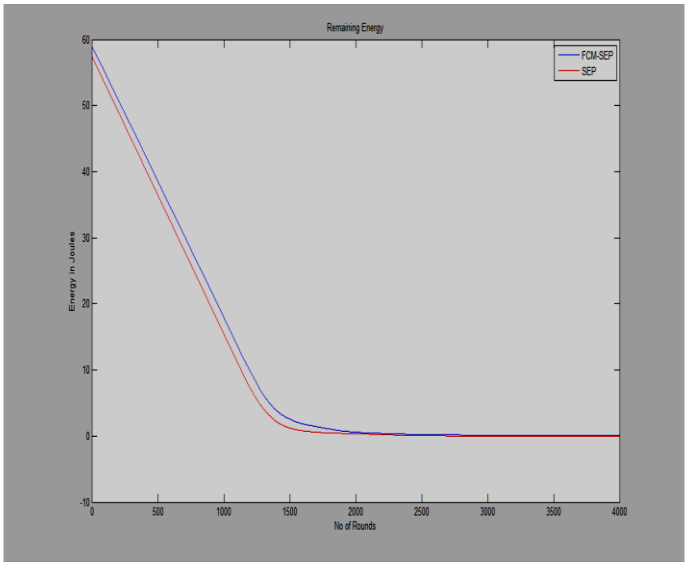

Figure 4 Remaining Energy

Simulation results show that there is 3.9% improvement in remaining energy of FCM-SEP protocol over SEP Protocol.

5. CONCLUSION

The network performance is evaluated by conducting the Simulation using MATLAB (R2013a). Fuzzy C-Means based Stable Election Protocol (FCM-SEP) is compared with the SEP Protocol. Performance metrics used to compare the results are Number of Alive nodes, Number of dead nodes and Total Remaining Energy of the nodes. Number of alive nodes has a direct effect on the lifetime of the network. Simulation results show that there is 9.3% improvement in number of alive nodes and 3.9% improvement in remaining energy in case of FCM-SEP over SEP. In the Future, Fuzzy C-Means can be used in the other variants of SEP protocol for energy efficient networks.

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