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Energy-Efficient in wireless sensor networks using fuzzy C-Means clustering approach

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Abstract: Extending the lifetime of a wireless sensor networks remains one of the prominent research topics in recent years. Clustering has been proven to be energy-efficient in sensor networks since data routing and relaying are only operated by cluster heads. The present paper focuses on proposing two algorithms. In the former nodes organize themselves into clusters using fuzzy c-means (FCM) mechanism then a randomly node chooses itself cluster head in each cluster since initially all nodes have the same amount of power. Then the node having the higher residual energy elects itself cluster head. All non-cluster head nodes transmit sensed data to the cluster head. This latter performs data aggregation and transmits the data directly to the remote base station. The second algorithm which is a improvement of the former uses the same principle in forming clusters and electing cluster heads but operates in multi-hop manner when it routes data from cluster heads to the base station. Simulation results show that the proposed algorithms improve energy consumption and consequently resulting in an extension of the network lifetime. In addition, the second algorithm proves its ability to be applied in large-scale wireless sensor networks.

Keywords: Wireless Sensor Networks, Fuzzy C-Means, Clustering, Lifetime

1. Introduction

In recent decades, the need to observe and monitor hostile environments has become essential for many military and scientific applications. The nodes used must be independent, has a miniature size and can be deployed in a random manner in the dense and monitored field. A special class of ad hoc networks called wireless sensor networks comes to the rescue. They have appeared thanks to technological developments such as miniaturization of electronic components, reducing manufacturing costs and increasing performance and storage capacity, and energy calculation.

A wireless sensor network consists of a massive number of small, inexpensive, self-powered devices that can sense, compute, and communicate with other devices for the purpose of gathering local information to make global decision about a physical environment [1]. Data gathered may be a variety of environment conditions such as temperature, humidity, pressure, movement, light, density of air pollutants, early fire detection, and so on [2].

The constraints imposed by these networks are very well known: very limited computation, communication, storage capabilities, and energy resources. This last aspect, which limits the lifetime of the network and therefore its utility, has received considerable attention by the research community over the last several years. The design of energy-aware protocols, algorithms, and mechanisms, with the goal of saving as much energy as possible, and therefore extending the lifetime of the network, has been the topic of many research studies [3].

The hierarchical organization of the sensors, grouping them and assigning those specific tasks into the group before transferring the information to higher levels, is one of the mechanisms proposed to deal with the sensors limitations and is commonly referred to as clustering [4-6]. In this context came our proposed algorithms named respectively proposed1 and proposed2. They consist of forming clusters applying fuzzy c-means mechanism followed by selecting cluster heads using residual energy of nodes in each cluster but they differ in their mode of transmitting data to the base station. The remainder of this paper is organized as follows: in the next section, related works about the clustering-based routing protocols have been presented. Section III describes in detail the proposed algorithms. Simulation results are

discussed in section IV. Finally, section V concludes the paper.

2. Related Works

Several clustering-based routing in wireless sensor networks has been addressed by a number of researchers [5,6]. Heinzelman and al [7,8] proposed a typical clustering scheme called Low-Energy Adaptive Clustering Hierarchy (LEACH). It is an energy-efficient protocol designed for sensor networks with continuous data delivery mechanism and no mobility. In LEACH, nodes organize themselves into local clusters, with one node acting as the local cluster-head. LEACH includes randomized rotation of the high-energy cluster-head position such that it rotates among the various sensors in order to not drain the battery of a single sensor [9]. A Hybrid Energy-Efficient Distributed clustering approach (HEED) [10] introduces a variable known as the cluster radius, which defines the transmission power to be used for intra-cluster broadcast. The initial probability for each node to become a tentative cluster head depends on its residual energy, and final cluster heads are selected according to the intra-cluster communication cost. HEED relies on the assumption that cluster heads can communicate with each other and form a connected graph; realizing this assumption in practical deployments could be tricky.

In [11], the authors propose a new energy-efficient clustering approach (EECS) for single-hop wireless sensor networks, which is more suitable for the periodical data gathering applications. EECS extends LEACH algorithm by dynamic sizing of clusters based on cluster distance from the base station. D. C. Hoang & al in [12] apply an approach based on fuzzy C-Means for clustering calculation, cluster head selection and data transmission. Threshold sensitive Energy Efficient sensor Network protocol (TEEN) [13] is a hybrid of hierarchical clustering and data-centric protocols designed for time-critical applications. It is a responsive protocol to sudden changes of some of the attributes observed in the wireless sensor network such as temperature [6]. However, TEEN cannot be applied for sensor networks where periodic sensor readings should be delivered to the sink. An adaptive threshold sensitive Energy Efficient sensor Network protocol (APTEEN) [14] that is an extension of TEEN is used for both periodic and responsive data collection. We just mention this non-exhaustive list of clustering protocols. For more reading refer to [5,6].

3. Proposed Protocols

This manuscript proposes two energy-efficient algorithms for the extension of the lifetime of a wireless sensor networks based on fuzzy C-means clustering approach. Before explaining the principle of the proposed approaches, we briefly describe the fuzzy c-means algorithm used to accomplish clustering task.

3.1. Fuzzy C-Means Algorithm

FCM clustering protocol is centralized clustering algorithm, the base station computes and allocates sensor nodes into clusters according to the information of their location and the cluster head is assigned to the node having the largest residual energy [12]. Consider a network of N nodes and partitioned into c clusters. The objective function of FCM algorithm is to minimize the following equation [15]:

$$J_m = \sum_{i=1}^{c}\sum_{j=1}^{N}\mu_{ij}^{m}d_{ij}^{2} \qquad (1)$$

where
μ_{ij} is node j's degree of belonging to cluster i.
d_{ij} is the Euclidean distance between node j and the center of cluster i.
The z_j centroid of the jth cluster, is obtained using (2).

$$z_j = \frac{\sum_{i=1}^{N}\mu_{ij}^{m}o_i}{\sum_{i=1}^{N}\mu_{ij}^{m}} \qquad (2)$$

The degree μ_{ij} of node j respected to cluster is calculated and fuzzified with the real parameter m>1 as below:

$$\mu_{ij} = \frac{1}{\sum_{k=1}^{c}\left(\dfrac{d_{ij}}{d_{kj}}\right)^{2/(m-1)}} \qquad (3)$$

The FCM algorithm is iterative and can be stated as follows [15]:
1- Select m   (m >1); initialize the membership function values μ_{ij}, i = 1,2,..., n ;j = 1,2,..., c.
2- Compute the cluster centers z_j , j =   1,2,..., c, according to (2).
3- Compute Euclidian distance d_{ij} , i =   1,2,..., n ; j = 1,2,..., c
4- Update the membership function μ_{ij} , i =   1,2,..., n ; j =   1,2,..., c   according to (3).
5- If not converged, go to step 2.

3.2. First Proposed Algorithm

The first proposed algorithm mimics Leach protocol but the difference lies in the mode of clusters formation and cluster heads selection. It operates into three steps. In the first step clusters are formed by the Fuzzy C-Means method. Each clusters contains a set of a nodes and the number of nodes is not necessary equal in the clusters. In the second step, a cluster head is initially elected in each cluster. Since all nodes have the same amount of energy, a random number is generated between 1 and the number of nodes in each cluster and the node corresponding to this number elects itself cluster head. This is done only at the beginning but after a rotation mechanism based on the remaining energy is applied to select the next cluster head. Non-cluster head nodes send gathered data to the corresponding cluster head.

In the third step, cluster heads receive and aggregate data then communicate it in single hop manner to the remote base station.

The pseudo-code of the first proposed algorithm is described as follows:

Apply FCM algorithm to form clusters.

Each cluster c(i) contains a number of nodes, i=1, …, nc

Initially all nodes have the same amount of energy.

//cluster heads selection

maxE=zeros(1,nc) ;

maxE is a row vector contains nc zeros

it_max: maximum number of iterations

ET: is the totalnetwork energy

while(it≤it_max || ET>0)

for i = 1 to nc do

if it==1

r=rand*length(c(i)) ;

ch(i)=c(i).r ;

else

for j=1 to length(c(i))   do

if maxE(i)<c(i).E(j)

maxE(i)=c(i).E(j)

end if

end for

ch(i)=maxE(i)

end if

end for

// non CHs send data to CHs

for i = 1 to nc do

for j=1 to length(c(i)) do

c(i).j send data to ch(i)

end for

end for

// CHs send data to BS

for i = 1 to nc do

ch(i) aggregates and transmits directly data to BS

end for

end while

Figure below illustrates the operating mode of the first proposed algorithm where cluster heads send data directly to the base station.
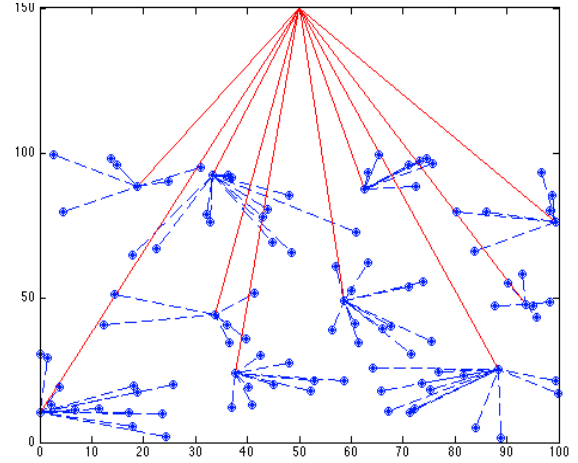

Figure. 1. *Single hop with clustering.*

3.3. Second Proposed Algorithm

The second proposed protocol uses the same principle of clusters formation and cluster head selection than the first protocol. The difference is in the data transmission from the CHs to the base station. Data transmission is made by multi-hop. Each cluster head sends aggregated data to the closest cluster head in the direction of the base station. This is repeated until it reaches the base station.

Since the mode of clusters formation and the cluster heads selection is the same as the first algorithm, we present below only the pseudo-code of the part concerning the data transmission from the cluster heads to the base station.

Calculation of distances between CHs and distances between CHs and BS

for i=1 to nc

for j=1 to nc do

$$d(i,j) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

end for

$$dBS(i) = \sqrt{(x_i - x_{BS})^2 + (y_i - y_{BS})^2}$$

end for

for i=1 to nc do

if dBS(i)==mindBS

ch(i) sends directly to BS

else

for j=1 to nc do

if (i≠j && d(i,j)==min(i) && dBS(i)>dBS(j))

ch(i) sends data to ch(j)

end if

end for

end if

end for

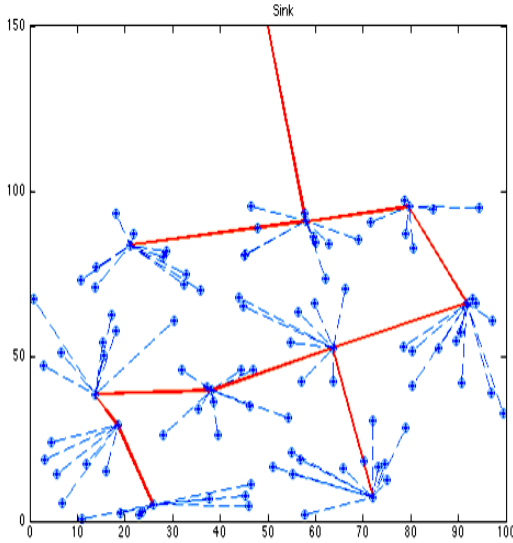Figure below represents the principle of the second proposed algorithm.

Figure. 2. Multi-hop with clustering

The blue dashed lines represent intra-cluster communication while the red bold lines represent the inter-cluster heads communication and the base station.

We emphasize that both proposed algorithms are centralized and controlled by the base station.

4. Evaluation

Before discussing the simulation part, we make some assumptions then we present the used radio model.

4.1. Assumptions

The following properties are assumed in regard to the sensor network being simulated:

Both sensor nodes and base station are stationary after being deployed in the field.

Base station is located outside the area of the sensor nodes.

The wireless sensor network consists of the homogeneous sensor nodes.

All sensor nodes have the same initial energy.

Base station is not limited in terms of energy, memory and computational power.

The radio channel is symmetric such that energy consumption of transmitting data from node X to node Y is the same as that of transmission from node Y to node X.

Each sensor nodes can operate either in sensing mode to monitor the environment parameters and transmit to the base station or cluster head mode to gather data, compress it and forward to the base station.

4.2. Radio Model

The radio model we have used is similar to [8]. There are two different radio models. The free space model and the multi-path fading channel model. When the distance between the transmitter and receiver is less than threshold value d_0, the algorithms adopt the free space model (d^2 power loss). Otherwise the algorithms adopt the multi-path fading channel model (d^4 power loss). So if the transmitter sends a k-bit message to the receiver up to a distance of d, the energy consumption of the receiver can be calculated by the following equations:

$$E_{TX} = \begin{cases} k.E_{elec} + kE_{fs}d^2 & if \quad d < d_0 \\ kE_{elec} + kE_{mp}d^4 & if \quad d \geq d_0 \end{cases} \tag{4}$$

Threshold value d_0 is given by:

$$d_0 = \sqrt{\frac{E_{fs}}{E_{mp}}} \tag{5}$$

Where

E_{elec} is the amount of energy consumption per bit to run the transmitter or receiver.

E_{fs} and E_{mp} represent the energy consumption factor of amplification in the two radio models.

E_{RX} is the amount of energy consumption in receiving a packet with k bits. This is given by (6).

$$E_{RX} = k \; . \; E_{elec} \tag{6}$$

4.3. Simulation Results and Analysis

The proposed algorithms are evaluated by simulating a network of 100 nodes. Sensor nodes are dispersed in an area of 100 x 100 m^2 shown in figure 1, the base station is located at (50,150), so it is at least 50m from the closest sensor node. The number of clusters is chosen equal 10, which is the square root of the total number of nodes. Each sensor node transmits a 1000 bit message. The initial energy supplies to each sensor node is 0.1J. Table 1 gives all simulations parameters.

For the evaluation of the algorithms two metrics have been chosen: energy consumption and number of alive nodes.

Figure 3 shows the simulation of the energy consumption of nodes in each round for both approaches comparing with the direct transmission algorithm. The total energy dissipated of proposed1 and proposed2 is better than direct transmission algorithm, and also the total energy dissipated of proposed2 is a few better than that of proposed1.

Table 1. *Simulation parameters*

Parameters	Values
Network size	(100×100) m^2
Number of nodes	100
Initial energy	0.1 J
Data packet size	1000 bits
E_{elec}	50×10^{-9}
E_{fs}	10^{-11}
E_{mp}	1.3×10^{-15}
EDA	5×10^{-9}

EDA represents energy data aggregation.
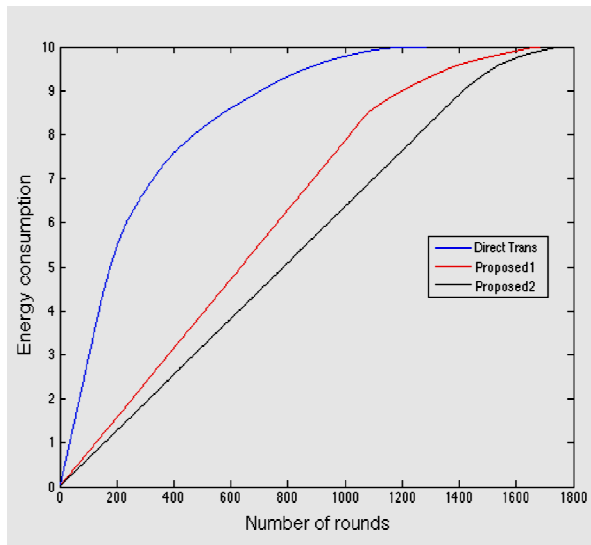
Figure. 3. *Energy consumption vs. number of rounds*
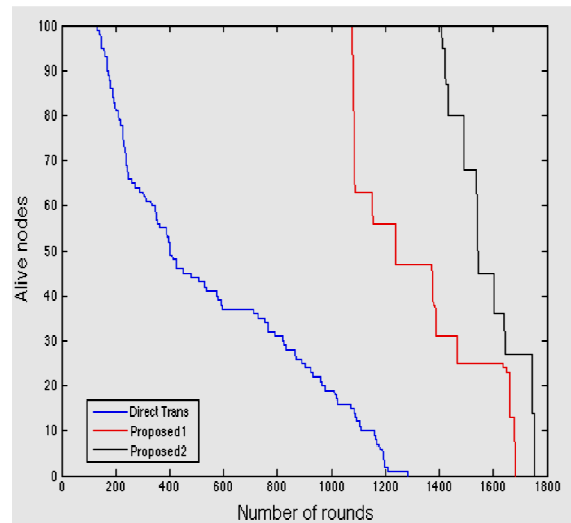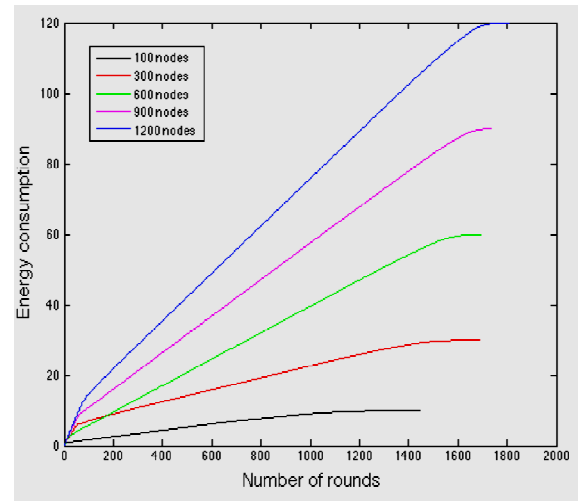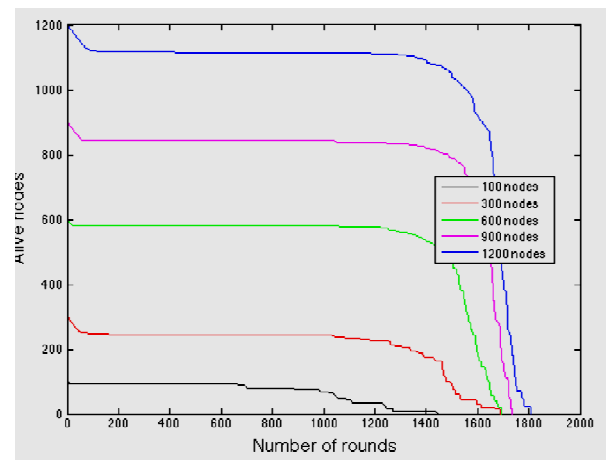

Figure 4. *Number of alive nodes vs. number of rounds*

Figure. 5. *Energy consumption vs. number of rounds*

From the simulation result shown in figure 4 and given by table 2, we observe that the first node dies in direct transmission algorithm after 131 rounds while in proposed1 and proposed2 first node dies after 1077 and 1411 rounds respectively. We also observe that the last node dies in direct transmission algorithm after 1283 rounds while in proposed1 and proposed2 last node dies after 1681 and 1753 rounds respectively. Therefore, we note that proposed2 is about 4.11% more efficient in term of network lifetime than proposed1 and about 26.82% than direct transmission algorithm.

In the following part, we simulate proposed2 algorithm in five different network sizes. We assume that nodes are deployed in an area of 300×300 m^2; the base station is located at (150,400). The two metrics mentioned above are used for evaluation.

Figure 5 represents the variation of energy consumption with respect to the number of rounds in different networks containing respectively 100, 300, 600, 900 and 1200 nodes.

Figure 6 below shows the variation of alive nodes versus number of rounds for the precedent five network sizes.

Figure 6. *Number of alive nodes vs. number of rounds*

Table 2. *Duration of first and last node die in the network*

	Direct Transmission	Proposed1	Proposed2
First node dies	131	1077	1411
Last node dies	1283	1681	1753

5. Conclusion

In wireless sensor networks, it is recommended to apply a clustering scheme specially when you are confronted to the problem of power consumption. In this paper, we have proposed two approaches that consist to form clusters by FCM algorithm and choose cluster heads by residual energy of nodes but they differ in their data transmission mode to the base station. Simulations results show that ours schemes offer a better performance than the direct transmission algorithm in terms of energy consumption and network lifetime. Moreover, scalability of the proposed2 algorithm is also verified over simulation.

The second proposed approach can be further improved by adopting some intelligent algorithm such as genetic algorithms or ant colony specially to find the shortest path between the cluster heads and the base station.

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