A new approach for decreasing energy in wireless sensor networks with hybrid LEACH protocol and fuzzy C-means algorithm

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Abstract: The optimum use of energy in wireless sensor networks (WSNs) is very important. The recent researches show that organising the network nodes in some clusters leads to higher efficiency of energy and finally it increases the lifetime of the network. So, controlling the number and the location of the clusters head (CHs) and also the size of the clusters about the node number leads to a balance in energy use of the CHs and increasing the lifetime of the network. Clustering-based routing protocols are energy-efficient protocols that improve the lifetime of a wireless sensor network. The objective of the clustering is to minimise the total transmission power by aggregating into a single path for prolonging the network lifetime. In this paper, fuzzy C-means (FCM) algorithm is used for the optimum numbers of the CHs and the location of them. Using FCM in WSNs helps changing the LEACH protocol parameters while execution. The results show that the hybrid algorithm increases the lifetime of the network in comparison to the LEACH algorithm.

Keywords: wireless sensor networks; WSNs; fuzzy C-means; FCM; LEACH protocol; cluster head.

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1 Introduction

The wireless sensor networks (WSNs) which are used for supervising and controlling an environment include many sensor nodes, which are distributed in the environment and process the information and send the gathered information from the sensors to the base station (BS) (Akyildiz et al., 2002; Yick et al., 2008). A WSN transmits the sensed information to the end users in the form of data-packets. The number of packets is directly proportional to the transmission rate of the nodes in the WSN (Das and Misra, 2013).

The clustering protocols are used for decreasing the energy use in WSNs. The sensors are divided into some areas which are named cluster head (CH) and after each happening the sensors of each area send their information to the CH and it transfers the information to the BS (Rajshekhar Chalak et al., 2010). The communication protocols play important role in efficiency and increasing the lifetime of the WSNs. So, it is important to design efficient protocols in energy use of the WSNs because this not only reduces the total energy use of the network, but also it makes the energy use be balanced among the network nodes and increases the lifetime of the network. The protocols based on the clustering play considerably important role in the decrease of the energy use in the network. In such protocols the election of a node as a CH is very important in the lifetime and scaling of the network. LEACH protocol is one of the known algorithms in clustering the WSNs (Heinzelman et al., 2000). LEACH is a distributable algorithm in which the CH role is not bound just for a single node and in each period any of the nodes decides on being CH randomly. The mechanism is designed in a way that guarantees the CH role for each node. In this method, the nodes organise themselves in a cluster shape and a node takes the CH responsibility which reduces the energy use of the network and lengthens the lifetime of the network. Another version of LEACH is LEACH-C algorithm (Heinzelman et al., 2002). In this algorithm, the central control centre decides the node to be the CH. The control centre gathers the information of the all nodes and decides the CH according to this information and also the whole status of the network. So, the LEACH-C algorithm increases the lifetime of the network. HEED algorithm (Younis and Fahmy, 2004) is another clustering algorithm for the WSNs which are a distributed algorithm.
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Each node decides itself as the CH according to the left energy rate to the primary energy for itself.

Clustering is an efficient method for the designing the useful and scalable protocols in WSNs (Singh et al., 2010; Jiang et al., 2007). Clustering decreases the communication overflow and this leads to the decrease in energy use and the wave interference. In many applications, clustering is a method for grouping the nodes which are located in low distance from each other to get use of the related data and remove the redundant data. So, the routing protocol based on the clustering method is one of the most important methods in decreasing the energy use of the WSNs. In this paper, a clustering protocol according to a combination of the fuzzy C-means (FCM) (Wang, 2010) algorithm and the LEACH algorithm is presented. In clustering hybrid protocol, it is trying to balance the energy in the cluster and finally lengthen the lifetime of the network and the coverage of it.

We organise the general structure of this paper as follows: in Section 2, we describe related works; in Section 3, the LEACH algorithm is introduced; in Section 4, the FCM algorithm is described; in Section 5, the proposed solution is explained; in Section 6, evaluate and results present and finally in the Section 7, conclusions is presented.

2 Related works

WSNs are consisting a number of clusters of sensor nodes that can communicate with each other via wireless link. Each cluster is represented by a node as a head of the cluster to maintain a direct communication with the BS and as well as with other CHs. Naturally efficient choice of CH is an important issue of the performance of the consumed WSNs. In the recent years, the researchers have been used different algorithms to solve clustering in WSNs.

FGRA is a secure, energy-efficient scheme for multipath routing in sensor networks. It uses fuzzy logic (FL) for generating decisions of forwarding or withholding packets to get a robust, efficient and scalable number of nodes (Ramachandran et al., 2008). Researchers have proposed a solution for decreasing the energy use in WSNs according to FL (Kumar et al., 2011). They have used FL for clustering and the election of the CHs. Their suggested algorithm defines the CH nodes in some sessions according to different parameters like energy rate and the number of the neighbours and create the balanced clusters holding CHs with higher energy that the normal algorithms. The results of the examinations show that the proposed algorithm is more efficient than LEACH and EEDS protocols, and can decrease the energy use of the network to the least rate. In the other research, the authors use the FL and give an efficient algorithm for clustering the nodes in the WSNs (Singh et al., 2012). The algorithm uses the distance and remained energy parameters of each node and decreases the energy use of the network and balances the energy use of the network which finally leads to the long lifetime of the network. The evaluation results proved that using the FL the lifetime of the network increases in comparison to the LEACH algorithm.

Researchers (Shamroukh et al., 2012) have presented a Fuzzy clustering method based on FL for the WSNs. In this structure, the sensor nodes are grouped in a series of clusters and a node is selected as CH. In that method election of the right CH considerably decrease the energy use of the network, which leads to the increase of the lifetime of the network. The clustering method based on FL in their paper includes three basic steps of energy, network lifetime and the centre scheme of the nodes. In Sharma
and Kumar (2012), a method for clustering the nodes according to fuzzy-based master CH election leach (F-MCHEL) is used to increase the lifetime of the network which is a basic parameter in sensor networks. In this method of clustering, different parameters like the balance of the size of the clusters and the energy of them are taken into consideration deeply. EATM is another method that partitions the network into clusters, and uses concepts intertwined with the concepts of facility location theory, in a distributed manner, for reducing the energy dissipation of the event monitoring nodes by reducing their average transmission distance (Das et al., 2013). Research (Godbole, 2012) has presented a communication protocol for the WSNs according to FL which is based on clustering the network sensors according to the remained energy of each node and the distance of them from the BS. In this protocol the sensor nodes use more balanced energy in comparison to LEACH protocol, so the quality reduction of the services of the network by the time in comparison to the LEACH algorithm would be acceptable. In the presented protocol, it is assumed that the sensors on the network are the sensors with data production rate. The sensor nodes would always have data to send to the BS. In the suggested protocol, it is trying to decrease the energy use. Researchers (Ye et al., 2005) have used the FL to design an efficient and scalable protocol for WSNs. They have used clustering to reduce the overflow of transfer of the data and finally the energy use and interference of the clustering among the nodes. In many applications, the clustering is a good solution for clustering the nodes near each other to use the related data and remove the single step routes. The data volume transmitted to the station has been developed by a combination of the nodes in the CH and the energy use of the resources has decreased.

A new energy-aware WSN routing protocol, reliable and energy efficient protocol (REEP) is proposed in Zabin et al. (2008). REEP makes sensor nodes establish more reliable and energy-efficient paths for data transmission. In Pan et al. (2010), researchers proposed a novel energy efficient clustering scheme for single-hop WSNs. A new cost function is presented to balance the load among the CHs and prolongs the network lifetime significantly against the other clustering protocols such as LEACH. This method manages the potential of nodes to semi-equal. Therefore the death of all nodes happens in the same interval, which maximises the lifetime of the overall network. A distributed clustering algorithm for WSNs is proposed in Alim et al. (2013) by taking into account of the lossy nature of wireless links. First, formulate the one-hop clustering problem that maintains reliability as well as saves energy into an integer program. Then a metric-based distributed clustering algorithm is proposed to solve the problem and adopt a metric called selection weight for each sensor node that can indicate both link qualities around the node and its capability of being a CH. EEAODR is an improved protocol that considers the power level of each node in the network while calculating the route in order to increase the lifetime of the network. The optimisation function is used to select the energy efficient path among the all discovered by considering different factors such as nature of the packets, their size and distance between nodes (Dhurandher et al., 2009).

3 LEACH protocol

LEACH Protocol is the first and the most famous protocol based on clustering in WSNs in which clustering is distributed (Das and Misra, 2013). In LEACH Protocol the CHs are elected randomly from the nodes and all nodes have the same chance to be elected as CH and each node communicates with the BS via the CH. In LEACH protocol the nodes are
randomly distributed in an area and then are grouped in clusters and each node is a member of a cluster and each cluster has a CH (Younis et al., 2006). The election of the nodes as CH is done according to the distance of the nodes. The non-CH nodes (normal nodes) transfer their data to the CH. So, the only overflow for them is the communication inside the cluster.

The most important application of the LEACH Protocol is gathering the data from the environment and the sensors elect themselves as the local CH according to a presumed probability (Bandyopadhyay and Coyle, 2003). Each sensor in this protocol produces a random number and decides on besides that either to be the CH. The CH nodes need more energy than the other ones. So, the election of a node as a fixed CH leads to drainage of the energy and death of the node (dead node). The energy balance takes place by election of many nodes as CH. As the election of CH takes place randomly, it is possible for a part of a network not to have any CH at a time and the density of CHs in another part to be more. Totally there is no regulation for the topology changes and the remained energy of the sensors which can affect the election of the nodes. The LEACH Protocol has been able to make an election of the CHs happen in the network. The LEACH Protocol operation is divided into some periods and each one begins with the formation of the clusters and at this time the clusters are organised. Following clustering session, data transfer takes place in which the normal nodes send their data to the CHS and the CHs send the complete packets to the BS to reduce the volume of the data which must be sent to the BS. In LEACH protocol the time schedule for sending the data of the sensors via code division multiple access (CDMA) or time division multiple access (TDMA). The CH election takes place by a probability function. Each node, selects a random number between zero and one and if the chosen number is less than \( T(n) \), the node would be selected as the CH. The CH is elected by the equation (1).

\[
T(n) = \begin{cases} 
  p & \text{if } n \in G \\
  1 - p \left( r \bmod \frac{1}{p} \right) & \text{otherwise}
\end{cases}
\]

(1)

In equation (1), \( p \) is the probability of being elected as CH, \( r \) is the period and \( G \) is the group of the nodes which have not been CH in \( 1/p \) late period.

The radio model used for the communication of the nodes affects the efficiency of the network. So, we use the equation (2) to calculate the remained energy of the CHs.

\[
E_{\text{TX}} = \begin{cases} 
  E_{\text{elect}} + E_{\text{bl}} l d^2 & \text{if } d < d_0 \\
  E_{\text{elect}} + E_{\text{mp}} l d^4 & \text{if } d \geq d_0
\end{cases}
\]

(2)

In equation (2), \( E_{\text{TX}} \) is the transferred energy volume, \( E_{\text{elect}} \) is the energy in the electronic circuit of the sender or the receiver for sending or receiving each bit, \( E_{\text{bl}} \) and \( E_{\text{mp}} \) depends on the model of the sender, \( l \) is the length of the sent or received packets and \( d \) is the distance between the sender and the receiver which is calculated by equation (3) taking into consideration \( d = d_0 \).

\[
d_0 = \sqrt{E_{\text{bl}} / E_{\text{mp}}}
\]

(3)

Also the energy for receiving \( l \) bit in receiver node is introduced by equation (4).
It is assumed that in each period, CHs receive only one packet from the nodes. So, this leads to the differences in used energy for sending data to the BS.

4 Fuzzy C-means

The FCM clustering algorithm is the most used algorithms for diagnosing the related data in the different clusters (Wang, 2010). In fact clustering means division with no supervision. Using the clustering of data to the groups which resemble to each other in the favoured parameters, is a famous method in FCM; they depend on the primary condition and favour an optimum local point and group N data into C cluster in high speed (Chen et al., 2009; Hoang et al., 2010). FCM algorithm is a basic method for many methods of clustering. There are different methods for this algorithm, but all have same procedure and try to decide like as follows for many of the clusters:

- finding points as the core of the clusters (these points are the average points of each cluster)
- binding any data to the cluster, which is placed in minimum distance.

In the FCM clustering algorithm, first some clusters are elected randomly for the needed points and then data are bound to them according to the distance to the clusters. Repeating this procedure, it is possible to find a new core calculating the average data and make them as new clusters. This is continued till there is no change in the data. In clustering algorithm, there is a target function which introduces the data distance of the clusters. The target function in this algorithm is defined as equation (5).

\[
J_w = \sum_{i=1}^{c} \sum_{j=1}^{n} u_{ij}^m \| x_j - v_i \|^2 
\]

The following conditions must also be true.

\[
\sum_{i=1}^{c} u_{ij} = 1 \quad \forall j = 1, \ldots, n 
\]

In equation (5), \( c \) is the number of the clusters, \( n \) is the data number, \( m \) is the fuzzy rate (\( m \) is a real number more than 1 and in most cases \( m \) is elected as 2), \( x_j \) is the \( k \)th data, \( v_i \) is the \( i \)th cluster, \( u_{ij} \) is the membership grade of the \( j \)th data in \( i \)th cluster. In all clustering algorithms of Fuzzy clustering, the number of the clusters is defined first and the clusters take their primary value. Then, using equations (7) and (8), the values are updated and this procedure continues till the difference between the data is fixed.

\[
u_i = \frac{\sum_{j=1}^{n} (u_{ij})^m x_j}{\sum_{j=1}^{n} (u_{ij})^m} \]
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\[
\mu_{ij} = \frac{1}{\sum_{l=1}^{m-1} \left( \frac{x_l - y_l}{\|x_j - y_j\|} \right)^{2/(m-1)}}
\]  

(8)

FCM clustering is usually used for finding the structure in the data which are not labelled. In this situation, it is trying to put the data into different clusters to reach a target function which holds the minimum value. So, selecting the distance Fuzzy functions, it is possible to cluster the data optimally.

**Figure 1** The flowchart of the proposed algorithm
5 Proposed solution

In LEACH protocol each CH sends the data directly to the central station. So, if the sensor nodes are distributed normally in an area, some of the CHs can have long distance from the central station. According to the energy consumption model in the WSNs, this makes the difference in energy use of the network and leads to unbalanced load in the network. This difference in energy use is seen obviously after some sessions. If the nodes start working with the same energy, the node which has more distance from the BS, run out of their energy earlier and be the dead nodes and this reduces the efficiency of the network. Also, in LEACH Protocol the nodes are selected randomly and as the CHs use more energy, if a node of low energy is elected as the CH, the remained energy of it will end and this will lead to an unbalanced network.

To solve the problems in LEACH Protocol, a combination of LEACH Protocol and FCM algorithm is used. In the proposed protocol to solve the energy problems, the nodes which are located in more distance from the BS and have lower energy than the other nodes, have less chance to be CH. So, in clustering session of the nodes using FCM, the nodes chose to be normal node or a CH. Any node of 1 or 0 probability to be elected as CH selects a status according to fuzzy probability vector and reaches the stable status. So, the algorithm is repeated in fixed times, and in the time of repetition all nodes choose their status and make the network. Figure 1 represents the proposed algorithm flowchart.

LEACH protocol runs with many rounds. Each round contains two states (Das and Misra, 2013): cluster setup state and steady state. In cluster setup state, it forms clusters and select CHs. In steady state, it transfers data. The time of second state is usually longer than the time of first state to minimise the overhead. LEACH is based on rounds and system repeats clustering and transmission for each round.

Figure 2 The pseudo code of LEACH

<table>
<thead>
<tr>
<th>(1) Set-up phase:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Based on ( T(n) ), threshold, CHs are selected</td>
</tr>
<tr>
<td>• All CHs broadcast ADV message to all non-CH nodes</td>
</tr>
<tr>
<td>• All non-CH nodes select their CHs, based on RSSI of ADV message</td>
</tr>
<tr>
<td>• After selecting cluster, it (non-CH node) sends Join-REQ back to CH</td>
</tr>
<tr>
<td>Now, CHs create TDMA schedule &amp; send it to the all non-CH nodes</td>
</tr>
<tr>
<td>(2) Steady-state phase:</td>
</tr>
<tr>
<td>• Sensor nodes begin sensing &amp; transmitting data to CHs as per their TDMA Schedule</td>
</tr>
<tr>
<td>• After receiving data, CHs aggregates data to the BS in one-hop manner, thus reducing the number of transmissions &amp; hence saving energy</td>
</tr>
<tr>
<td>• After certain time, N/W goes back to set-up phase again &amp; enters another round</td>
</tr>
<tr>
<td>• Each cluster communication, using different CDMA codes to reduce the interference from other cluster nodes</td>
</tr>
</tbody>
</table>

After the combining FCM and LEACH, The quasi code of the hybrid protocol for decreasing the consumed energy in WSNs includes the following steps.
Using FCM in WSNs helps changing the LEACH protocol parameters while execution. In the combines protocol, it is assumed that the whole forming operation and management of the clusters take place in BS. In the suggested protocol the target is to make the structure of the nodes and the CHs distributed in a way to make the energy use of the network to be minimised. In any period, each node according to FCM and based on three basic descriptive of energy, distribution and the centre localisation in comparison to the neighbours participates in the CH election process. Each node compares its status with the status of the other nodes in the neighbourhood and if the energy of it is more than the neighbour node, introduces itself as the CH node. In hybrid protocol, first the CHs are elected based on the energy level and the distance from the nodes and then the clustering starts by binding the nodes to the nearest cluster. But in the LEACH protocol this probability is static and cannot decide according the position and the energy level in the network.

6 Evaluation and results

In this section efficiency of the LEACH Protocol and hybrid protocol is evaluated. In hybrid protocol and LEACH algorithm, there are some parameters affecting the efficiency of the network. The values for these parameters are shown in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network size</td>
<td>100 × 100</td>
</tr>
<tr>
<td>BS location</td>
<td>50 × 50</td>
</tr>
<tr>
<td>Number of sensor nodes</td>
<td>100</td>
</tr>
<tr>
<td>$E_{\text{elec}}$</td>
<td>50 nJ/bit</td>
</tr>
<tr>
<td>$E_{\text{fs}}$</td>
<td>10 pJ/bit/m$^2$</td>
</tr>
<tr>
<td>$E_{\text{mp}}$</td>
<td>0.0013 pJ/bit/m$^4$</td>
</tr>
<tr>
<td>$M$</td>
<td>[1–2]</td>
</tr>
</tbody>
</table>
The operation of the hybrid protocol and the LEACH is shown in Figure 3 from increase in the lifetime of the sensor network points of view. As it is obvious, the hybrid protocol has decreased the number of the dead nodes in comparison to the LEACH.

**Figure 3** The diagram of comparison of the number of dead nodes (see online version for colours)

![Graph showing comparison of dead nodes between LEACH and Hybrid Protocol](image)

In Figure 4, the number of the created CHs in hybrid protocol and LEACH are compared in the different periods. As it is seen, the number of the CHs in hybrid protocol is better than LEACH.

**Figure 4** The diagram of comparison of the number of CHs in each period (see online version for colours)

![Graph showing comparison of CHs between LEACH and Hybrid Protocol](image)

To show the efficiency of the hybrid protocol and LEACH from a number of CHs points of view, the number of the CHs in Figure 5 is considered 500. As it is seen, the hybrid method could create more balanced CHs and this makes the nodes use energy more balanced and lengthen the lifetime of the network.
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Figure 5 The comparison the number of the CH in 500 periods (see online version for colours)

7 Conclusions

In this paper, a new protocol for decreasing the energy use in WSNs using the combination of LEACH Protocol and FCM is introduced which is the base of hybrid protocol of clustering the sensors according to the remained energy of each node and the distance of the nodes from the BS. In the hybrid protocol, the sensor nodes use more balanced energy in comparison to LEACH energy algorithm and at last this leads to increasing the lifetime of the network. The results of the examinations show that hybrid protocol is more efficient from energy use and lifetime of the network points of view.

References


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