DNRC: An Algorithm for Wireless Sensor Network Clustering Based on Dynamic Ranking of Nodes in Neighborhoods

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Abstract
Clustering of the nodes is one of the most prevalent approaches for increasing the lifetime of wireless sensor networks by properly managing their energy consumption. In this paper a new algorithm named DNRC is proposed for the sensor nodes clustering. This method is based on neighborhood clusters formation and ranking the nodes within a cluster to select cluster heads. The performance of the proposed algorithm is checked and compared to other methods based on three conventional metrics and one new proposed metric of this paper.

Keywords:
Wireless Sensor Networks, Clustering, Energy Consumption, Lifetime of Sensor Network

1. Introduction

An important aspect of modern wireless sensor networks (WSN) is energy consumption management in order to increase the lifetime of the network. For the sensor networks employed in hardly accessible environments, such as outer planets or deep areas in oceans, the energy saving strategy should be considered as a very crucial scenario. Recent advancements in the electronics, control and communication of sensor nodes allow researchers to consider more efficient methods for the low cost and low energy operation of these networks [1]. As an approach to devise energy saving schemes for WSNs, clustering of the nodes has been investigated by researchers in recent decade [2-4]. Relative distances between the nodes in the network, and also to the base nodes, can be deduced by received signal strengths and can be used to perform the clustering task in WSN. Energy consumption of a sensor node can be decreased by sending the signal to a cluster head node instead of sending directly to the base station antenna. Selecting the most appropriate set of cluster heads and the set of associated nodes to each cluster head is the main basis of clustering in WSN. Environmental effects can incorporate uncertainties in the position or energy consumption of a sensor node. A prevalent approach is to use non-deterministic clustering methods due to the existence of uncertainty [5]. Recently, fuzzy logic based methods have been proposed for the clustering of WSN in order to increase its lifetime [6, 7]. Clustering based on the swarm intelligence [8-11], such as bee colony [10], is also investigated for the energy consumption optimization of sensor network.

Heinzelman et al [5] have introduced the LEACH as one of the most well known algorithms in this field of research. The main characteristics of the LEACH protocol is its being as a simple method of cluster formation and transmitting data. The selection of cluster heads in LEACH is mostly random. Therefore, it does not much consider the position, distances, and the energy remnant of a sensor node. However, it is obvious that consideration of such information about the state of network can be highly advantageous to the performance and lifetime of the WSN. There are many other algorithms, like HEED [12], which consider energy and communication costs of selecting a sensor as a cluster head node. Recently, an unequal clustering method, named EAUCF, for WSN based on fuzzy inference approach of Mamdani [13] is proposed by Bagci and Yazici [7]. In their proposed method, which itself is an improvement of CHEF algorithm [4], a fuzzy inference system is used to take energy remnant and distance to the base of the nodes as input variables and decide the competition radius of tentative cluster heads.

In this paper we propose a new clustering method which is simpler and more efficient than new methods such as EAUCF. The proposed method considers the closeness of nodes in order to set several initial clusters. Then the cluster head is selected by considering a ranking index composed of energy remnant, local distances to the cluster nodes, and the distance to the base station. In this way, the task of being a cluster head is circulated among nodes of the cluster. The clusters are also formed automatically in a homogeneous way in the area.

The next sections of this paper are presented as follows: In section 2 we present short introductory descriptions to some of previous wireless sensor network clustering algorithms in literature. In the section 3, the problem and WSN model description is presented. Section 4 describes the proposed method of this paper. In section 5, by simulating the proposed method and other previous protocols like LEACH and EAUCF, the performances are evaluated and compared. Concluding remarks are addressed in the section 6 of the paper.

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2. Related Works

One of the most famous clustering algorithms for increasing energy consumption efficiency of WSNs is the LEACH algorithm [5] which is based on randomly selection of cluster heads in a way that each node would be selected in period of rounds. It means that the probability of a node to be selected as a cluster head is determined in LEACH based on its previous selection statuses. The main characteristics of LEACH are localized coordination of cluster formations, random selection of cluster heads and their corresponding clustered nodes, and local data compression in clusters in order to decrease the direct communication to the base station. The advantage of LEACH over classic clustering algorithms is due to its energy utilization distribution adaptively. In [5] a first order radio transmission model for nodes of the sensor network is assumed in which the energy consumed due to data transmission through the channel is proportional to the square of the distance between the transmitter and receiver nodes. The channel is also considered to be symmetric between every two nodes in the network. Cluster head nodes aggregate data they receive from their associated nodes and then send the aggregated data to the base station. The selection of cluster heads is done by nodes themselves and each node decides about its role independent to the other nodes in the WSN. The decision is done based on the desired number of cluster heads in the whole network and the historical status of the node itself. In LEACH, the probability for a node n to be selected as cluster head in round r is determined as

$$P(n;r) = \begin{cases} \dfrac{C}{1 - C\left(r \bmod \dfrac{1}{C}\right)}, & n \in G \\ 0, & otherwise \end{cases}$$

where the C is the desired percentage of cluster head nodes in the network and G is the set of nodes which are not yet selected as cluster heads in the previous $\frac{1}{C}$ rounds of cluster formation. To decide for being a cluster head or not, the nodes calculate their $P(n;r)$ value in each round, produce a random number, compare the random number to $P(n;r)$ and if it is less than $P(n;r)$ the node will be assigned the cluster head role. This would result in a fair cluster distribution and hence fair energy consumption through the network as the nodes will die later.

Another clustering algorithm which is heterogeneity of WSN nodes are addressed is known as SEP algorithm [14]. In [14] some of nodes are assumed to have additional energy resources, so the initial situation could be heterogeneous. In SEP the probabilities of nodes to be selected as cluster heads are weighted by their energy remnant. In the LEACH algorithm [5] described above, the effects of possible energy resources heterogeneity are not considered. The main idea for introducing SEP has been to improve the clustering efficiency for the case of heterogeneous WSN. It is shown in [14] that the algorithms like LEACH which do not consider the heterogeneity of WSN suffer from instability when some of the nodes get out of energy. Compared to LEACH, the probabilities of advanced nodes (nodes with additional energy resources) and normal nodes are different in SEP. In fact the probability values for advanced nodes are multiplied by a factor of $1 + \alpha$.

In LEACH the numbers of clusters are considered as a predefined value by network user. However some of algorithms are proposed to modify the LEACH by calculating the optimum value for the number of clusters in the network. One of such modified algorithms is LEACH-G [15] which obtains the optimum number of clusters based on the radio model of the WSN. The numbers of clusters are optimized by means of multi-objective particle swarm optimization (PSO) algorithm in [16].

The overlapping of clusters is another issue in WSN clustering algorithms. Several algorithms tried to obtain a minimum overlap of neighboring clusters. On the other hand MOCA [17] is one of the algorithms which is based on the opposite idea that asserts the benefits of partial overlap between clusters. The overlap is shown to be beneficial particularly in the case of multi-hop communication allowance in the WSN.

Some the algorithms allow the nodes to decide to be a candidate cluster head before the final decision about assignment of that role. This means that the nodes are not selected as cluster heads immediately based on the probability values as is done in LEACH for example. Instead they decide based on probability values that they could be potentially a cluster head and in a next phase of algorithm the cluster heads are selected among those candidate set of nodes based on competition or some other subroutine. One of such algorithms is ACE [18] in which the migration of clusters and spawning are also established in its operations. Another interesting behavior in ACE protocol is that the nodes could be assigned to more than one cluster head; however they are constrained to follow a main cluster among those.

Utilization of fuzzy logic for WSN clustering is proposed in CHEF algorithm [4]. Besides the probabilities as used in LEACH, the CHEF uses a chance value calculated by means of fuzzy rules to select cluster heads in each round. The possible cluster heads then advertise their candidacy by means of a signal to the network. The nodes receive candidacy signals from other candidate codes and compete based on their chance values. The nodes with higher chance values compared to their competitors are selected to be cluster heads. CHEF utilizes two fuzzy variables to determine the chance values of the nodes: energy remain of nodes, and local distance which is the summation of distances between the node and its neighbor nodes in a neighborhood of radius r. The value of r is calculated based on the network area, number of nodes and number of desired clusters.

EAUCF [7] is an algorithm which tries to improve the idea of CHEF [4]. Compared to CHEF, in EAUCF the competition radius of each node is a dynamic quantity and is determined by means of fuzzy inference system of rules. In EAUCF, the fuzzy variables used as the inputs of inference system to determine the competition radius are energy remain and distances to the base station. In [7], various scenarios are simulated and improvements of the results compared to CHEF and other algorithms such as LEACH are shown. The scenarios include the case where the base station is in the center of the area of WSN and the head nodes send their data to the base station directly and without the use of relays, the case in which the base station is centered but the multi-hop and relayed communication is also allowed, the case in which multi-hop communication is allowed and base station is in the center but the density of nodes is considered differently to the case 1 and 2, and the case in which the base station is out of the region where sensor nodes are settled. Based on the simulation results of [7] one can observe that the main advantage of EAUCF compared to other algorithms is in its better resulting half time of network, i.e. the time the half of the nodes are alive and the other half are out of energy.

There are many other WSN clustering algorithms proposed in the literature which are not presented here. Various aspects and scenarios are considered in different algorithms. The interested reader can be referred to review articles [3] for further comparison of WSN clustering methods.

3. WSN model and the problem description

In this paper we use sensor network examples with fixed positions for the one base station and the sensor nodes. The sensor nodes are spread in the sensed area randomly. When a sensor node associates in a cluster, it sends its observation signal to the cluster head node of the corresponding cluster. The cluster head collects data from all sensor nodes in its cluster, aggregates and sends all to the base station. Sending a signal of l bits from a sensor node to distance d consumes energy E_T

$$E_T = \begin{cases} l\,E_{elec} + l\,E_{fs}\,d^2, & x \le d_o \\ l\,E_{elec} + l\,E_{mp}\,d^4, & x > d_o \end{cases} \tag{1}$$

where

$$d_o = \sqrt{\frac{E_{fs}}{E_{mp}}} \tag{2}$$

The energy consumed by a node to receive l bits of data is

$$E_R = l\,E_{elec}. \tag{3}$$

The values of E_{elec}, E_{fs}, E_{mp} and l are considered fixed and equal for all the sensor nodes in this study. Cluster heads however spend more energy due to the aggregated sum of bits they receive from their associated nodes. The aggregation energy E_{DA} per bit adds to the energy consumption of the cluster head. The initial energies E_i of all the sensors are also considered equal. The WSN parameter values used in simulations of this paper are shown in Table 1.

Table 1: Values of WSN parameters

Parameter	***Value***
E_i	0.5 J
E_{elec}	50 nJ
E_{fs}	0.1 nJ
E_{mp}	0.00013 nJ
E_{DA}	0.5 nJ
l	4000

4. Proposed Method (DNRC)

In order to decrease energy consumption and increase the lifetime of the sensor network we propose a clustering method which considers three main information from the network: energy remnant of each sensor, distances between neighbor nodes, distances of nodes to the base station. In practice, distances can be estimated by nodes from the strengths of signals they receive. The proposed Dynamic Neighborhood Ranking Clustering (DNRC) algorithm dynamically forms local neighborhoods of nodes, performs rankings within the neighborhoods, and selects cluster heads in each neighborhood (cluster). We use the word neighborhood to stress the fact that clusters in the proposed algorithm are formed based on closeness of nodes to each other. For the selection of cluster head in each cluster, the algorithm utilizes rank index r_i for each node. The rank of a node i in cluster j is calculated as

$$r_i = \frac{(E_i^{rem})^{\alpha}}{d_{i,B}^2\ D_{i,\{j\}}^2} \tag{4}$$

where E_i^{rem} is the energy remnant of node i, $d_{i,B}$ is its distance to the base node, and $D_{i,\{j\}}^2$ is the summation of squared distances between node i and all the nodes within its corresponding cluster j. It should be noted that in calculation of rank indices, the division by zero is better to be avoided by addition of a very small number to the distances. Also we normalized distances by dividing them to the radius of area, so they can have orders comparable to energies. The power α is used to adjust the effect of energy remnant compared to distances in ranking. Initially we set $\alpha = 1$, and then we further investigate effects of its variation.

The proposed clustering algorithm is as follows:

1- Set maximum desired number of clusters N_{max}, and the radius of neighborhood formation R.

2- *For* each alive node i, *if* it is not yet clustered, and *if* the number of current clusters N_{cl} is less than N_{max}, do:

2.1- $N_{cl} = N_{cl} + 1$, and add node i to the new cluster N_{cl} ($Cl_i = N_{cl}$).

2.2- *For* each alive node j, *if* $d_{i,j} \leq R$:

if node j is not yet clustered add it to cluster N_{cl} ($Cl_j = N_{cl}$).

else do nothing.

3- *For* each alive node i, *if* it is not yet clustered, and *if* the number of current clusters N_{cl} is equal to N_{max}, do:

3.1- Find the closest node j to the node i.

3.2- Set $Cl_i = Cl_j$.

4- For each cluster j, do:

4.1- Calculate rank index r_i for each node i within cluster j.

4.2- Set a node CH_j with the maximum rank as the cluster head of cluster j.

The proposed clustering algorithm performs in a way which has several advantages:

- By assigning neighbor nodes in a cluster, the next clusters are formed not in the vicinity of previously clustered nodes. So the cluster heads assigned by this method will not be close to each other, as it may happen in some methods like LEACH.
- The calculations of the proposed method are simple, and they don't require for example fuzzy logic calculations in methods like EAUCF. The number of algorithm parameters of the proposed method (3 for N_{max} , R and α) are much less than the number of parameters in fuzzy logic based method (as many as 40 parameters for the EAUCF [5]).
- By dynamic ranking of the nodes, the task of being cluster head will be circulated properly among the nodes of the cluster. This circulation will increase the lifetime of the WSN.

5. Simulation and Performance Evaluation

In this section the results of simulation of WSN examples associated with clustering algorithms are presented and compared. To show the superiority of the proposed method, we utilize that, LEACH and EAUCF all on the same WSN examples. For comparison, we have chosen LEACH because of its prevalence fame in the literature, and EAUCF for its being one of recent methods.

To quantify and compare the performance of WSN clustering methods, several indices have been used in the literature. The time when first node dies (FND), time when half of the nodes are alive (HNA), and the time when the last node dies (LND) are the three main metrics of WSN clustering performance in the literature. We further propose using a time weighted metric (TWM) which integrates all of such metrics. It is desirable to have more alive nodes at later times, so we sum over the number of alive nodes in each time weighted by the time itself

$$TWM = \sum_{t=0}^{LND} t\, n_a(t) \qquad (5)$$

in which $n_a(t)$ is the number of alive nodes in time t.

The WSN used for the first simulation is settled on a square area of size 200×200, has 50 sensor nodes spread randomly over the area. The base node is positioned in the center of the area. This WSN is shown in the figure 1.

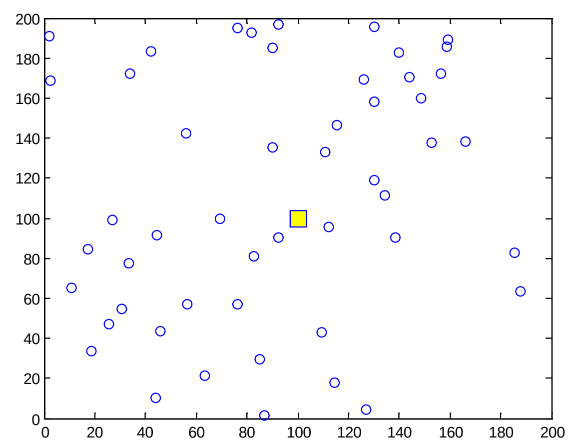

Fig. 1 The WSN used for simulation1

For the parameters of the clustering algorithms, we set percentage of cluster heads p in the LEACH protocol equal to 0.1, and all the parameters of EAUCF algorithm (including fuzzy membership parameters) are set equal to their values in [5]. For the parameters of the proposed DNRC method we set $R = 20$ and $N_{max} = 15$, and $\alpha = 1$. The results of simulation by LEACH, EAUCF, and DNRC are shown in the figure 2. In the figure 2 the number of alive nodes in each round is plotted for the algorithms. By simulating several times we found that the general behavior of these curves would not be changed for fixed parameters.

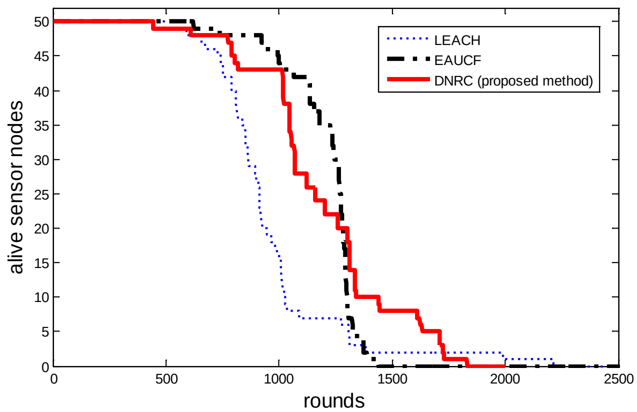

Fig. 2 Comparison of number of alive nodes versus rounds for LEACH, EAUCF, and DNRC (the proposed method) in clustering the WSN of simulation 1.

We observe that LEACH method provides a larger LND metric, but that is not practically useful because the most of the nodes are died sooner. EAUCF was mainly proposed to improve the HNA metric of the system [5]. As it is seen the HNA for EAUCF is also longer for the results shown in figure 2. By proposing DNRC, we aim to improve the overall behavior of the WSN in a more balanced way. It can be observed in figure 2 that DNRC has a better LND compared to EAUCF, and better HNA compared to LEACH. In order to check the better overall performance quantitatively, the values of obtained metrics for these results are shown in Table 2. As it is seen the TWM has the best value for DNRC.

Table 2: Metric values for results of simulation 1.

	LEACH	*EAUCF*	*DNRC*
FND	492	622	445
HNA	912	1271	1162
LND	2214	1441	1832
TWM	25472475	37348259	38005553

For simulations 2 to 13, we observed the variation of metrics by changing the three parameters of DNRC i.e. R, N_{max}, and α. The change in each simulation has been done only on one of these parameters, and the rest have been set similar to values of simulation 1. In Table 3 the results of simulations 2-13 are shown. It is observed that generally the selected values in simulation 1 have had the best performance. Also we see that variation of α does not produce meaningful effects.

Table 3: Simulations by varying the parameters of DNRC (R, N_{max}, and α)

	change	*FND*	*HNA*	*LND*	*TWM*
Sim2	R=5	526	1210	1799	37486807
Sim3	R=10	518	1194	1832	37797632
Sim4	R=15	496	1186	1837	37884002
Sim5	R=25	554	1184	1691	36761406
Sim6	R=30	495	1173	1617	35187254
Sim7	N=3	362	855	1265	19803285
Sim8	N=5	484	929	1289	23877980
Sim9	N=8	577	989	1527	28746804
Sim10	N=10	551	1025	1642	31625357
Sim11	α =0.1	459	1142	1820	37972330
Sim12	α=2	472	1163	1794	37830807
Sim13	α=20	450	1152	1820	37997079

6. Conclusions

In this paper we proposed a new clustering algorithm for wireless sensor networks in order to increase their lifetime. The proposed method (DNRC) is based on dynamical ranking of nodes in neighborhood clusters. The neighborhood clusters are formed based on closeness of the nodes, and the ranking is performed based on a ranking index composed of energy remnant, distance to the base station, and the summation of local distances to other nodes in the cluster. The high rank nodes in each round are selected as cluster heads, and the signal transmission is performed. The performance of the proposed DNRC algorithm is compared to previous methods based on four metrics of FND, HNA, LND, and the TWM which is proposed in this paper. The results of simulation show the superiority of the proposed method. Also the effects of varying parameters of DNRC on the performance have been investigated.

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