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Sensor networks

A Node Overhaul Scheme for Energy Efficient Clustering in Wireless Sensor Networks

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Abstract—Clustering of wireless sensor network nodes, a fundamental operation, is aimed at achieving load balancing and prolonged network lifetime. Low-energy adaptive clustering hierarchy protocol, the prominent standard, achieves these. An improved protocol, balance cluster formation, provides the additional advantage of equal size clusters, but at the cost of overlapping of clusters. This letter presents a node overhaul scheme that achieves load balancing and energy efficiency while also maintaining uniform size clusters without any overlapping. The proposed solution first forms initial clusters and later refurbishes the initial clusters based on a second best choice cluster head, wherever applicable. The results so obtained show a substantial improvement in network lifetime and node death rate as compared to other simulated methods.

Index Terms—Sensor networks, energy efficiency, load balancing, network lifetime, uniform size clusters (USCs).

I. INTRODUCTION

Wireless sensor networks consist of a large number of spatially distributed autonomous sensor nodes deployed to monitor the physical environmental conditions [1]. Due to the highly resource constrained nature of a sensor node, a wireless sensor network needs to be well designed from energy conservation perspective [2]. In the literature, clustering methodology has been investigated to conserve the energy of sensor nodes in the deployed wireless sensor network.

Heinzelman *et al.* [3] have proposed low-energy adaptive clustering hierarchy (LEACH) protocol, considered as the umbrella protocol for clustering approaches, to extend the network lifetime. LEACH states that the resultant clusters should be of same size to load balance the network for better energy consumption in nodes, which has been also emphasized by [4]–[6]. However, LEACH and its various variants do not guarantee the formation of equal size clusters due to the their random nature. Pal *et al.* [7] proposed a balanced cluster size formation (BCF) solution, which focuses on developing clusters with balance in size. In BCF, the cluster formation is carried out in two steps. First is initial cluster formation, and the second one is rescue phase. In the first step, that is, initial cluster formation, nodes will join the nearest cluster head according to the received signal strength of advertisements, and each cluster can have maximum $\mathrm{Th}_{\mathrm{cluster}}$ member nodes (MNs), which is given by the following equation:

$$\mathrm{Th}_{\mathrm{cluster}} = \frac{N}{X} \tag{1}$$

where N denotes the number of nodes in the network, and X represents the count of cluster heads. It is possible that a few nodes may remain unclustered due to the $\mathrm{Th}_{\mathrm{cluster}}$ restriction. These nodes will then go into the rescue phase, where each unclustered node will join the cluster head, which is situated at a distance less than or equal to $\mathrm{Th}_{\mathrm{distance}}$ from the unclustered node and has MNs less than $\mathrm{Th}_{\mathrm{cluster}}$. If the joining node does not satisfy this condition, in the rescue phase, then the node will join the nearest cluster head. The BCF solution achieves energy efficient network along with better cluster quality as compared to LEACH but might not warrant crisp cluster boundaries, which leads to an increase in intracluster communication distance.

The work in this letter presents an uniform size clustering solution that creates clusters with crisp boundaries while reducing total intra-cluster communication distance as compared to BCF. In the proposed solution, the cluster formation process has been carried out in the following two steps: The first is the initial cluster formation phase, and the second is the cluster refurbish phase. The output of the initial cluster formation phase of the proposed solution is different as compared to the output of initial cluster formation of BCF. In the proposed solution, all the nodes are assigned with a cluster head as it happens in case of LEACH protocol, but there will be a few unclustered nodes in BCF approach because of threshold $\mathrm{Th}_{\mathrm{cluster}}$. The idea of the cluster refurbish phase of the proposed solution is to allow extra nodes (MNs—$\mathrm{Th}_{\mathrm{cluster}}$) of large clusters to join other clusters according to the second best choice of cluster heads. Experimental results confirm that the proposed solution has uniform size clusters (USCs); thus, the approach is named as LEACH-USC), along with reduced intracluster communication distance as compared to BCF. Also, the proposed LEACH-USC has lower node death rate and increased network lifetime as compared to LEACH and BCF. The rest of this letter is organized as follows: Section II dictated the problem statement, and Section III describes the proposed; thus, the approach is named as LEACH-USC solution in details. Section IV compares the output of cluster formation, cluster quality, and the performance of the proposed LEACH-USC approach with other protocols. Finally, Section V concludes this letter.

II. PROBLEM STATEMENT

Various protocols have been developed based on the principle of clustering, but most of them have an assumption that in each cluster there is always an equal number of nodes [3], [5], [6]. However, due to the random nature of clustering algorithms, clusters of unequal sizes

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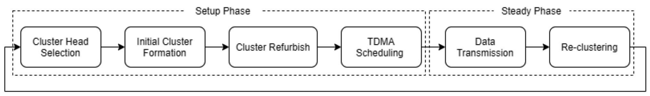

Fig. 1. Sequence of operations in the proposed LEACH-USC.

are normal, and this makes network load unbalanced, thus reducing the network performance.

Pal *et al.* [7] have shown the effect of cluster size on the number of time slots per node during a round time and it corroborates that in case of small size clusters, the number of time slots per node in a round is more as compared to large size clusters. The analysis shows that small size clusters consume more energy than large size clusters, as more time slots per node implies more transmissions, and the area under small clusters is oversensed while the area of large size clusters is undersensed during the same round.

The BCF [7] solution balanced the size of clusters with the help of two thresholds: $\mathrm{Th}_{\mathrm{cluster}}$ and $\mathrm{Th}_{\mathrm{distance}}$. The problem with this method is that equal size cluster creation is strongly dependent on these two parameters. $\mathrm{Th}_{\mathrm{cluster}}$ limits the number of nodes that can join clusters initially and, as a result of the leftout nodes, are randomly distributed in the network, which have to be handled in the rescue phase. These leftout nodes join clusters based on the joining condition which further depends on $\mathrm{Th}_{\mathrm{distance}}$ and $\mathrm{Th}_{\mathrm{cluster}}$. As a consequence of rescue phase, the clusters are of overlapping nature and do not have crisp boundaries. Furthermore, the balancing of clusters in terms of their sizes has direct dependency on $\mathrm{Th}_{\mathrm{distance}}$ [7]. An increase in $\mathrm{Th}_{\mathrm{distance}}$ will increase the number of balanced clusters, but it simultaneously increases the intracluster communication distance, which is an undesirable effect [7].

In order to resolve these issues, a uniform size clustering approach has been proposed in this work, which has clusters of uniform size, unlike LEACH, and clusters with crisp boundaries, unlike BCF.

III. PROPOSED UNIFORM SIZE CLUSTERING APPROACH

The proposed LEACH-USC approach has the following three objectives:

1) to generate clusters of uniform size (as in [7]);
2) to achieve clusters with crisp boundaries (as in [3]);
3) longevity of the network lifetime (as in [3] and [7]).

The operation of the proposed strategy has been depicted in Fig. 1. Cluster head selection depends on the probabilistic approach as also performed by LEACH and BCF. In the initial cluster formation operation, all the nodes join the nearest cluster head. As a consequence of probabilistic cluster head selection and assigning the nodes to the nearest clusters head, clusters of different sizes exist after the completion of initial cluster formation operation like the LEACH approach, but there will be no node without a cluster head, unlike the BCF approach. In the cluster refurbish operation of the proposed approach, clusters will be reorganized to obtain USCs with the goal of sending the nodes from the a large clusters to the other clusters according to the second best cluster head. First, the largest cluster among all clusters has been identified, and then, the distance between the MNs of the cluster and the rest of the cluster heads are calculated. This is done in order to find second best choice of cluster heads. The k-nodes [MN—$\mathrm{Th}_{\mathrm{cluster}}$], which have least communication distance to other cluster heads, will be assigned to respective second best cluster heads. Consequently, nodes near the cluster boundary will be assigned to other cluster heads.

Algorithm 1: Cluster Refurbish Phase.

Input: Number of cluster heads (X), Number of nodes in each cluster (CLUSTER[ ]), $\mathrm{Th}_{cluster}$
Important Variables: $largest$, MN, SecondBestCH[ ], k
Result: Uniform Size Clusters

Sort CLUSTER[ ] in Descending order
for *i=1; i ≤ X; i++* **do**
  largest = i
  MN = CLUSTER[largest]
  for *j:=1; j ≤ MN; j++* **do**
    SecondBestCH[i]=Distance to Second Best Cluster Head
  end
  Sort SecondBestCH[ ] in Aceneding Order
  k = MN - $\mathrm{Th}_{cluster}$
  if $k > 0$ **then**
    Allocate second best cluster head to first k nodes from sorted SecondBestCH[ ]
    Update CLUSTER[ ]
  end
  Remove the CH from the list from further processing
  Sort CLUSTER[ ] in Descending order
end

Algorithm 1 explains the working of the cluster refurbish process. The inputs provided in the algorithm includes: number of cluster heads (X), number of nodes in each cluster (CLUSTER[]), $\mathrm{Th}_{\mathrm{cluster}}$. First, the largest cluster is identified. Then, the second best distance of the MNs of the largest cluster is found so that they can join the second best cluster head. These distances are then arranged in ascending order and this step is necessary to ensure that nodes, which are closer to the clusters other than their respective clusters will join them and not the one which are farther away from them. Finally, the first k nodes ($k = \mathrm{CLUSTER[largest]} - \mathrm{Th}_{\mathrm{cluster}}$) from SecondBestCH[] will be sent from the largest cluster to their new clusters according to the second best distance. This process will continue until we have all the clusters of uniform size.

There may be 02 cases. In the first case, the number of nodes is divided completely by the number of cluster heads, i.e., remainder is zero then each cluster will have equal number of MNs, in the proposed LEACH-USC protocol. In the second case, the number of nodes is not completely divided by the number of cluster heads, i.e., remainder is not zero then (X-1) cluster heads will have equal sizes, and only one cluster will have a different number of MNs than the others. That is the reason why the name of the protocol is USCs.

After the cluster refurbish process, the TDMA schedule is created by each cluster head in the network according to the number of nodes in each cluster. In the data transmission phase, nodes will send data to their respective cluster heads, and cluster heads will aggregate the data and transmit the aggregated data to the base station. Eventually, reclustering is done to rotate the role of the cluster heads for the next round.

IV. SIMULATION RESULT

Table 1 gives a description of the main parameter setting to carry out the simulations. The simulation has been performed in MATLAB. All the nodes are homogeneous and are randomly placed in the field of

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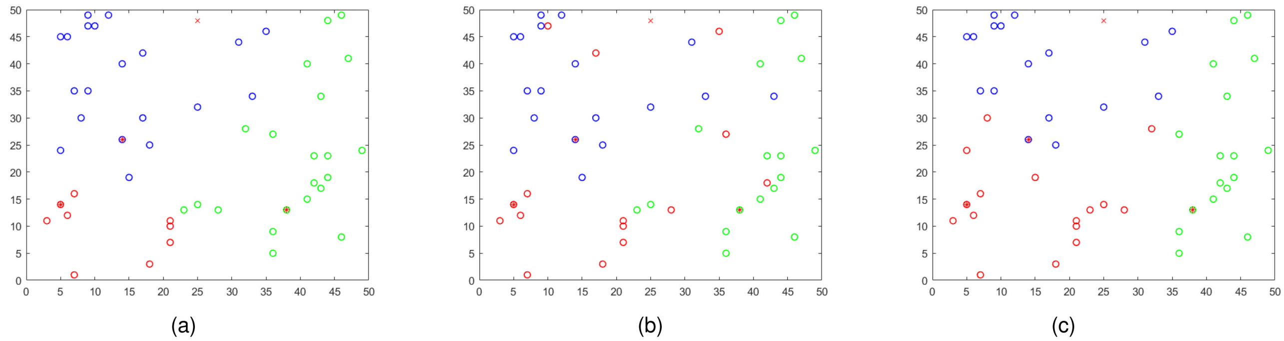

Fig. 2. Cluster structure in the network over a round. (a) LEACH. (b) BCF. (c) LEACH-USC.

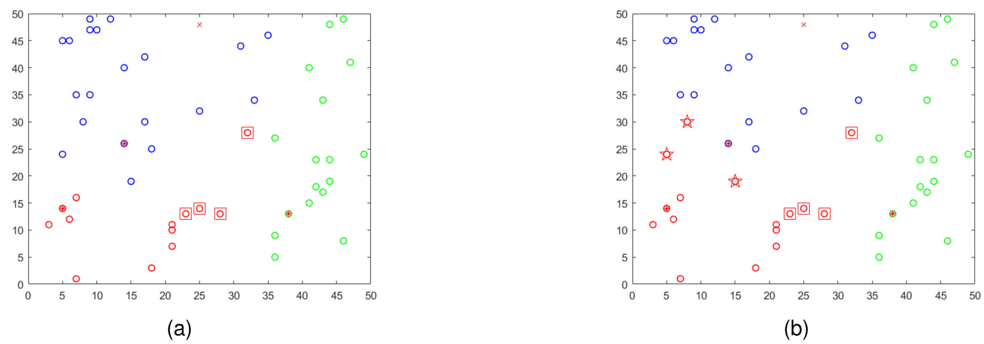

Fig. 3. Node overhaul in LEACH-USC. (a) Iteration1. (b) Iteration2.

Table 1. Network Parameters.

Parameter	Value
Number of Nodes (N)	50
Field Size	50 m × 50 m
Initial Energy	2J
Maximum Frame Length	N
Optimal Cluster Head [3]	5%

Table 2. Comparison of Cluster Quality (Cluster Size and Total Intra-cluster Communication Distance).

		Size of Cluster 1	Size of Cluster 2	Size of Cluster 3	Total Intra-Cluster Communication Distance
Run 1	LEACH	20	9	21	695
	LEACH-USC	17	16	17	758
	BCF	18	15	17	892
Run 2	LEACH	16	13	21	694
	LEACH-USC	17	16	17	735
	BCF	17	17	16	870
Run 3	LEACH	17	24	9	791
	LEACH-USC	17	17	16	889
	BCF	17	20	13	995

interest. For simulation of BCF, the value of $Th_{distance}$ is 40 m. Radio energy model described in [3] has been incorporated for simulation purpose. Result for the network performance comparison has been averaged over 30 repetitions or runs. First, the comparison of generated cluster structures and cluster quality [7] has been carried out between LEACH, BCF, and LEACH-USC, and then, the comparison of the network performance has been figured for with LEACH, BCF, ESCC [6], and LEACH-USC.

A. Comparison of Cluster Structures

In this section, a comparison has been made between the clusters so generated in a round between LEACH, BCF, and the proposed LEACH-USC. In Figs. 2 and 3, the hollow circle represents the sensor nodes: star in red color within the circle represents cluster heads, and cross in red color represents the base station. In this particular case, there are three clusters in the network: Cluster 1 represented in blue, cluster 2 represented in red, and cluster 3 represented in green.

In the case of LEACH, as shown in Fig. 2(a), Cluster 1 has 20 nodes, cluster 2 has 09 nodes, and cluster 3 has 21 nodes. On the other hand in case of BCF, as shown in Fig. 2(b), Cluster 1 has 18 nodes, cluster 2 has 15 nodes, and cluster 3 has 17 nodes. While in case of LEACH-USC, as shown in Fig. 2(c), Cluster 1 has 17 nodes, cluster 2 has 17 nodes, and cluster 3 has 16 nodes. In case of LEACH, the nodes join the nearest cluster as a result there is no assurance that the clusters so formed are of equal size. In the case of BCF, the clusters so formed are well balanced in terms of size because of rescue phase as the $Th_{cluster}$ parameter allows only limited number of nodes to join the clusters, and the $Th_{distance}$ parameters allow the unclustered nodes to join the best possible cluster, but the cluster boundaries are not crisp. In LEACH-USC, the clusters so formed are well balanced and have crisp boundaries also because the few nodes from the large clusters join the second best cluster.

In Fig. 3, the process of node overhaul has been depicted as the part of cluster refurbish phase of LEACH-USC. As shown in Fig. 3(a), 04 nodes, depicted as red circle in red square box, from the cluster 3, largest cluster, have been shifted to cluster 2. Similarly, 03 nodes, depicted as red circle in red star, from the cluster 1 have been shifted to cluster 2. As a result, LEACH-USC possesses the USCs with crisp boundaries.

B. Cluster Quality Comparison

Cluster quality is measured in terms of cluster size and total intracluster communication distance [7]. The comparison of the cluster quality of the three protocols LEACH, BCF, and LEACH-USC is shown in Table 2. In LEACH, the total intracluster communication

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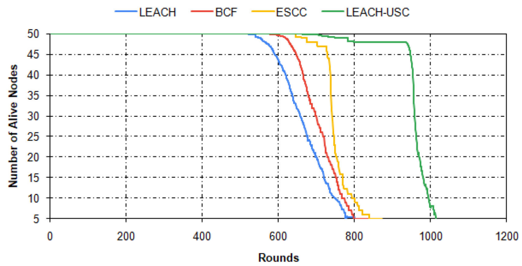

Fig. 4. Node death rate comparison for LEACH, BCF, ESCC, and LEACH-USC.

Table 3. Network Lifetime (FND, HND, and LND).

	LEACH	BCF	ESCC	LEACH-USC
FND	540	612	645	718
HND	674	721	746	962
LND	800	852	873	1015

is least among all other approaches, but the clusters are of uneven sizes, whereas in BCF, the total intracluster communication is highest, but the clusters are of balance sizes, while in LEACH-USC, the total intracluster communication distance is slightly higher than LEACH but much less than BCF but the clusters are of equal sizes. These results can be attributed to that fact that in LEACH, the nodes can only join the best possible clusters. In BCF, unclustered nodes are allocated to clusters with respect to the joining condition, which generates clusters of even sizes but with increased intracluster communication distance. On the other hand, in LEACH-USC, the nodes have to leave their best choice clusters and join the second best choice clusters.

C. Analysis of Network Performance

Metrices considered for the performance analysis and the comparison of proposed LEACH-USC with LEACH, BCF, and ESCC are as follows: node death rate, number of nodes alive over the rounds, and network lifetime, number of rounds for first node death (FND), half node death (HND), and last node death (HND).

Fig. 4 demonstrates the number of nodes alive over the rounds throughout the network lifetime. It can be observed from the figure that the node death rate in LEACH-USC is always better than LEACH, BCF, and ESCC throughout the network lifetime. This can be described to the fact that clusters obtained by LEACH-USC are well balanced in size as compared to LEACH due to which the overall network lifetime has been increased, and LEACH-USC outperforms BCF because not only are the clusters well balanced, the total intracluster communication distance is also less in comparison with BCF approach, which greatly enhances the network lifetime.

Table 3 shows the comparison of network lifetime, FND, HND, and LND, for LEACH, BCF, ESCC, and LEACH-USC. In comparison to LEACH, the percentage of improvement in LEACH-USC is 33%, 43, and 27% for first node death, half node death, and last node death, respectively. While, in comparison to BCF, the percentage of increment in LEACH-USC is 17, 33, and 19% for first node death, half node death, and last node death, respectively. In comparison to ESCC, the percentage of improvement in LEACH-USC is 11, 29, and 16% for first node death, half node death, and last node death, respectively. These figures clearly demonstrate network lifetime improvement in case of LEACH-USC.

V. CONCLUSION

The clustering approach, LEACH-USC, proposed in this article focuses on the balancing the load of the network by creating clusters of uniform size. The proposed LEACH-USC has established good quality clusters, in terms of cluster size and total intracluster communication distance. Simulation results show that LEACH-USC in comparison to LEACH has higher FND, HND, and LND by 33, 43, and 27%, respectively, whereas in comparison to ESCC scheme, these values are 11, 29, and 16% higher for FND, HND, and LND, respectively.

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