Hierarchical Cluster-based Routing in Wireless Sensor Networks

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I. Introduction

Our hierarchical cluster-based routing (HCR) technique is an extension of the LEACH [1] protocol that is a self-organized cluster-based approach for continuous monitoring. In LEACH, the network is randomly divided into several clusters, where each cluster is managed by a cluster head (CH). The sensor nodes transmit data to their cluster heads, which transmit the aggregated data to the base station. In HCR, each cluster is managed by a set of associates and the energy-efficient clusters are retained for a longer period of time; the energy-efficient clusters are identified using heuristics-based approach. Moreover, in a variation of HCR, the base station determines the cluster formation. A Genetic Algorithm (GA) is used to generate energy-efficient hierarchical clusters. The base station broadcasts the GA-based clusters configuration, which is received by the sensor nodes and the network is configured accordingly. For continuous monitoring applications, the simulation results show that HCR is more energy efficient than the traditional cluster-based routing techniques.

II. HCR Protocol

The main objective of the HCR protocol is to generate energy-efficient clusters for randomly deployed sensor nodes, where each cluster is managed by a set of associates called a head-set. Using round-robin technique, each associate member acts as a cluster head. CH receives messages from the cluster members and transmits the aggregated messages to a distant base station (BS). As all the transmissions are single-hop, cluster members transmit short-range broadcast messages and CHs transmit long-range broadcast messages. The head-set approach can be a good solution for clusters where the CH dies during a round.

Since the role of a CH is energy consuming, after a specified number of transmissions, a new set of clusters are formed. In other words, the clusters are maintained for a short duration called a *round*. A round consists of an *election* phase and a *data transfer* phase. In an election phase, the sensor nodes self-organize into a new set of clusters, where each cluster contains a head-set. In data transfer phase, the head-set members transmit a specified number of long-range transmissions to BS.

A. Election Phase

During an election phase, clusters are created using a threshold function as given in (1).

$$T(n) = \frac{p}{1 - p\left(r \; mod \frac{1}{p}\right)} \; , \forall n \in G \tag{1}$$

where, p is the difference of the desired percentage of the cluster heads, p_c, and percentage of retained clusters, p_r. Initially p_r is 0, as there are no clusters in the network, r is the current round, and G is the set of nodes that have not yet become head-set members for the last $1/p$ rounds.

First, each node generates a random number, which is between 0 and 1. If the random number is less than $T(n)$, the node becomes a head-set member and acts as a CH for this election phase. Second, each selected CH broadcasts a short-range advertisement. The sensor nodes may receive advertisements from one or more CHs. Third, each sensor node chooses its CH on the basis of the signal strengths of the received advertisements. Fourth, the sensor nodes transmit short-range acknowledgments to inform their CHs about their decision. At this stage, the clusters for the current round are determined and each head-set has one associate member. Fifth, the CHs that have relatively large cluster sizes select a pre-defined number of additional head-set members for their clusters; the additional head-set members are chosen based on the signal strength of the acknowledgment messages. The selected head-set members cannot become head-set members until all the remaining nodes have become CHs. An *iteration* is defined as a duration in which all the nodes have become CHs. Sixth, each CH creates a TDMA schedule for the head-set members, as well as the remaining cluster members. Seventh, CHs broadcast their TDMA schedules to their members.

At the end of election phase, each head-set member checks if it has sufficient energy for next round. If the energy of any head-set member falls below the given threshold value, it is removed from the head-set; the remaining head-set members update their schedules accordingly.

B. Data Transmission Phase

During data transmission phase, the member nodes transmit data to their CHs and the CHs transmit aggregated data to the base station. First, member nodes transmit data according to their TDMA schedule. Second, CH receives the messages from the member nodes. As head-set members become CH on round-robin basis, only CH receives the messages and the remaining head-set members turn off their radios. Third, CH transmits the aggregated data to the base station. Fourth, CH checks the remaining energy. If the energy level is less than the given threshold value, CH will remove itself from the head-set. Fifth, the outgoing CH informs the incoming CH about its decision to remain the head-set member or become a cluster member. If the outgoing CH withdraws from the head-set, the remaining head-set members update their schedules accordingly.

At the end of round, all the clusters are not destroyed; however, each cluster is retained for the number of rounds equal to the head-set size. In other words, the nodes of clusters with the head-set size of 1 become candidates in the next round but the nodes of the clusters with the head-set size greater than 1 do not participate in the next election. This approach reduces the number of elections and the burden of long-range transmissions is more efficiently distributed among the nodes. Moreover, for the next election, the percentage of headers is decreased according to the number of retained clusters. The retaining of clusters has shown a significant amount of improvement as compared to the LEACH protocol. For performance evaluation, HCR-1 represents a protocol that contains a head-set but energy-efficient clusters are not retained. Whereas HCR-2 represents a protocol that contains the head-set members and energy efficient clusters are also retained.

C. Genetic Algorithm (GA) for Hierarchical Clusters

In this variation of HCR, the base station determines the clusters configuration, which is broadcasted to the sensor nodes. The GA is used to create energy-efficient clusters for a given number of transmissions. The nodes are represented as bits of a chromosome. The head and member nodes are represented as 1s and 0s respectively. A population consists of several chromosomes and the best chromosome is used to generate the next population. The fitness of the chromosome is based on the estimated energy consumption, which is determined by several fitness parameters such as node density, transfer distance, variance in node densities and transfer distances, and current energy levels. Based on the survival fitness, the population transforms into the future generation. Initially, each fitness parameter is assigned an arbitrary weight. However, after every generation the best fit chromosome is evaluated and the weights for each fitness parameter are updated accordingly.

a) Fitness: The fitness of a chromosome is designed to minimize the energy consumption and to extend the network life time. A few fitness parameters are as follows: a) D - the sum of all distances from sensor nodes to the sink, b) C - the cluster distance, the sum of the distances from the nodes to the cluster head and the distances from the CHs to the sink, c) SD - standard deviation within cluster distances, d) E - estimated transfer energy that is consumed to transfer the aggregated messages from the cluster to the sink, and e) T - the number of transmissions assigned by the base station. The chromosome fitness, F, is a function of all the above fitness parameters, which is formally defined in (2), as shown below:

$$F = \phi(f_i), \forall f_i \in \{C, D, E, SD, T\} \quad (2)$$

Equation 2 is simplified as follows:

$$F = \sum_i \alpha(w_i, f_i), \forall f_i \in \{C, D, E, SD, T\} \quad (3)$$

The initial weights for fitness parameters are assigned arbitrarily; however, after every generation the best fit chromosome is evaluated and the weights for fitness parameters are also updated.

III. Results

We simulated LEACH and the variations of HCR protocols. The simulation results show that HCR is more energy efficient than LEACH. Figure 1 shows graphs of percentage of alive nodes with respect to the number of transmissions, for different network topologies such as grid, cluster grid, and random. For this experiment, the number of nodes were 200, the initial value of percentage headers was 5%, head-set size was 4, and the radio communication model as given in [1] was used. The graph of LEACH is the least energy efficient as compared to the other graphs. Part a) shows the confidence in GA approach where multiple simulations produced identical results, though only 5 are shown. HCR-1 shows a minor improvement over LEACH but the improvement is enhanced in HCR-2, where energy-efficient clusters are retained. GA's performance is the best, as it is adaptive to the network conditions. Moreover, GA's performance is more prominent for random topologies.

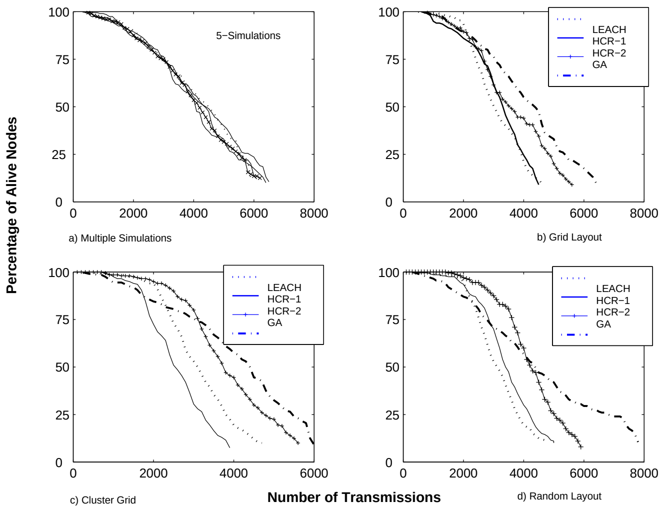

Fig. 1. Percentage of alive nodes with respect to the transmissions.

In our future work, we will incorporate other intelligent learning techniques for hierarchical clusters. Moreover, multi-hop routing will be investigated.

References

[1] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan. Energy-efficient communication protocol for wireless microsensor networks. In *Proceedings of the Hawaii International Conference on System Sciences*, January 2000.