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Global Optimization using Distributed Optimization Clustering Technique (DOCT) in Wireless Sensor Network

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Abstract: This paper presents a new clustering protocol for designing energy-efficient hierarchical wireless sensor networks (WSNs) by optimizing the distributed sensor network to satisfy the scalability and prolong the network lifetime in large-scale applications. The proposed approach is a distributed optimization clustering technique called DOCT, which is based on individual maximum weight and parameterized calculation. In the DOCT protocol, the size of clusters is based on the distance of nodes from the data link such as base station (BS) and the local node density. The cluster heads are elected based on the average mean distance from neighbors, remaining energy and the times of being elected as cluster head. The performance of the DOCT protocol is compared with some well-known clustering protocols in literature such as the LEACH, HEED, WCA, GCMRA and TCAC protocols. The results confirm that the ideas decrease the construction time and the energy consumption of clustering progress in sensor networks and consequently improve the lifetime of networks with limited resources and battery powered nodes in harsh and inaccessible environments.

Keywords: Optimization clustering Technique, Wireless Sensor Network, Global Optimization.

I. INTRODUCTION

Wireless Sensor Network (WSNs) attracted lots of researchers because of its potential wide applications and also many other challenges. Studies made earlier on WSNs mainly focused on all the technologies which are based on homogeneous WSN in which all the nodes have same system resources. Nowadays heterogeneous WSN is becoming more popular because of the benefits of heterogeneous WSNs with different capabilities in order to meet the demands of various applications. In sensor networks the nodes are usually battery energy supply based. In sensor networks the large number of nodes and their work environment are incompatible to energy recharge. Therefore power consumption is an important issue in Wireless Sensor Networks. More and More attention today is being paid to energy efficiency of Wireless Sensor Networks. document is a template. An electronic copy can be downloaded from the conference website. For questions on paper guidelines, please contact the conference publications committee as indicated on the conference website. Information about final paper submission is available from the conference website.

A wireless sensor network usually has energy constrained due to each sensor node requires battery with a limited energy supply to operate. Also, in some environments it may be inconvenient or impossible to recharge or replace sensor battery. However, the wireless sensor network should function long enough to accomplish the application requirements. Therefore, energy conservation is a main issue in the design of wireless sensor networks. There are different approaches to preserve energy usage and prolong the network lifetime in WSN.

The key approach to improve energy usage in WSN is the development of energy aware network protocols.

Typical clustering algorithms divide WSN nodes into two types: member nodes and cluster heads. The member nodes send data to their cluster-head, then a cluster-head aggregates the data and relays to the base station. Various clustering algorithms have been proposed for wireless sensor networks such as Low-Energy Adaptive Clustering Hierarchy (LEACH), An Energy-aware Clustering Technique for Wireless Sensor Networks and Hybrid Energy-Efficient Distributed (HEED) Clustering Approach presented a tree routing to avoid flooding network with path search and update message in order to conserve energy by using only link information between cluster head and members for packet forwarding. By using the cluster head and member link information only, intensive message exchanges of path search update processes are avoided and overhead of storing routing table and all other information that is very expensive to update. Also an unequal clustering and multi-hop routing scheme was presented to extend the network lifetime of WSNs. The authors presented the cluster head selection approach based on a cost function which considers the distance and energy usage. The proposed an approach to balance and reduce the energy consumption of clustered sensor networks. Since transmission range energy depends on consumption of sensor, all the cluster-heads are usually maintained at the centre of cluster. In each cluster, the highest residual battery level is selected with the help of node located at the centre area as the cluster-head.

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A maximum-Votes and Load-balance Clustering Algorithm (VLCA) was presented to reduce the number of clusters and prolong network lifetime. This algorithm selects the cluster-head by considering the number of member nodes and the residual battery level and then balance the workload among cluster-heads.
In clustering algorithms that were discussed previously and above, various sensor nodes are assigned to each cluster before the selection of cluster heads. The node with the best parameter value will typically be selected as a cluster head for data gathering and forwarding at each cycle.

II. BACKGROUND

1. The LEACH Protocol

The Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol [19] proposed by Heinzelman et al., is one of the basic clustering and routing protocols in WSNs and is used by many subsequent clustering and routing protocols. The main idea of LEACH is to select cluster heads by rotation and the high energy consumption for communicating with the BS is spreads among all the nodes. The operation of LEACH consists of rounds, and each round consists of two phases; the set-up phase and the steady-state phase. In the set-up phase the clusters are formed and in the steady-state phase data is delivered to the BS. In the set-up phase, each node decides to become a CH or not for the current round. The decision is based on the suggested percentage of CHs for the network and the times of being CH so far.

2. The HEED Protocol

The Hybrid Energy-Efficient Distributed Clustering (HEED) protocol [22], proposed by Younis and Fahmy, is a multi-hop clustering protocol which provides energy-efficient clustering. Unlike the LEACH protocol that randomly selects nodes as CHs; the HEED selects the CHs based on residual energy and intra-cluster communication cost. One of the main ideas of HEED is to achieve a balanced distribution of CHs throughout the network. Moreover, the probability of two nodes within each other's communication range becoming CHs at the same time is very small in the HEED protocol. Initially, Cprob, a percentage of CHs among all nodes, is set to assume that an optimal percentage cannot be computed. The probability of which a node becomes a CH is:

$$CH_{PROB} = Cprob. (E_{residual} / E_{max})$$

Where $E_{residual}$ is the estimated current energy of the node, and E_{max} is a reference maximum energy, which is equal for all nodes. The value of CH_{PROB} is not allowed to be less than a certain threshold and the threshold is inversely proportional to E_{max}. After that, each node executes several iterations to find the CH. On the other hand, CHs forward data to the BS using a multi-hop communication scheme [23].

3. The WCA Protocol

The Weighted Clustering protocol [24] proposed by Chaterjee et al. is based on nodes' neighbours' number and it considers the movement of nodes. The CH election is based on node degree (number of neighbors), transmit and receive energy and residual energy. To ensure that CHs is would not be under overload or high energy consumption conditions; there is a threshold number which shows the maximum number of cluster members. In other word the cluster size is limited [25, 26]. This fact that CH election process does not happen periodic causes reduction in calculations.

4. The GCMRA Protocol

The Energy efficient Grid based Clustering and Routing Protocol [27], proposed by Jana and Jannu, is a location-based method that divides the whole region into several grids. Nodes in every grid form a cluster. After the cluster forming step, cluster members elect the most suitable node as CH. According to the transmission range of nodes and considering the fact that every node in each cluster should be able to communicate with every node in eight-neighbour clusters, the grid size is calculated as R = x/2.83. On the other hand, the number of clusters can be calculated by knowing the grid and the network size, so the number of clusters in this method is fixed.

After finding the clusters, the nodes start by calculating the sum of distances from all nodes in a cluster. Finally the node with a minimum sum of distances becomes CH as long as its energy level is higher than a set threshold. This protocol uses a multi-hop routing scheme between CHs for shorter transmissions. As the relay nodes are between the source cluster and the BS, first, all nodes consider the BS as next-hop and if there is a CH in its radio range that is closer to BS, it becomes the next-hop. In fact, this approach focuses on reduction the communication range, and consequently reduction in long distance communication energy consumption [27].

5. The TCAC Protocol

The Topology-Controlled Adaptive Clustering (TCAC) protocol [28] was proposed by Dahnil et al. In this protocol all clustering steps are done assuming that the transmission energy of the nodes can vary. This method has three phases; the first is a periodic update. In order to reduce the effect of energy overhead (transmission start-up cost) and delay time, the periodic update is executed once in every D cycles. If this process were to execute in every cycle, the delay time and energy consumption would increase. In second phase, which is CH election phase, every node generates a random number between 0 and 1 and compares it with P (CCH). If the random number is less than P (CCH), the node becomes a candidate where the P (CCH) is the probability of becoming a candidate that is calculated as the ratio of residual energy of node and the average energy of all network nodes. After electing the candidates, the competition between them starts. The candidate with the most energy among all the candidate neighbors becomes the CH. In third phase, the CHs send a packet and each node that receives the packet responds it with another packet. Afterward the CH creates and broadcasts a list of nodes that send the packet and rank

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them based on the signal strength. Nodes use the list to find the best CH. This protocol focuses on the scalability of the network. In other word, increasing the number of nodes doesn't affect the efficiency of this protocol [28].

III. PROPOSED WORK

3.1. Phase A: Finding the All Nodes

In this phase, each node explores the network topology and gathers some information which includes the node distance from the BS, the number, and distance from its own neighbors. Distances are calculated by the RSSI equation [31, 32]

$$D_v = 10^{|RSSI-RSSI0| / 10.\eta}$$

Where RSSI is the received signal strength, RSSI0 is the signal attenuation for one meter distance from the source node and is the path loss exponent [33]. When the exploration phase begins, the BS broadcasts a packet (Start-Packet) to inform nodes of the beginning time and to let nodes calculate their distances from the BS. Then every node sequentially (based on ID) sends a packet to its neighbors during its own time slot (Hello-Packet) which contains its ID. All the other nodes monitor the channel during this time slot, so the neighbor nodes can receive the packet and store the information of the packet and the distance which is measured by RSSI in their local memory (Table 1). The nodes' information about the network topology depends on the neighbors ID, so if a node dies, the neighbor node should only know its ID and modify its calculations as the network is considered as being stationary. This phase is a significant preparation for the next phases and is done once for a network. After the exploration phase, DOCT operates in rounds. In every round, the clusters' construction should be rebuilt and new CHs should be elected. After clustering, nodes generate Data-Packets and the network works normally, so the remaining phases repeat in every round. At the end of this phase, each node forms a table such as Table 1, and then updates and uses it later.

Table 1: Primary nodes information from the network topology

Adjacent node including Neighbor Node	NODE ID	Distance (in meter)
1		
2		
-		
N		

Table 1 is updated only when a node dies in its neighbourhood. When the node's energy level falls to less than a predefined threshold, the node is considered dead and it notifies its neighbors by sending a corresponding packet (Death-Packet). Every node that is in its neighbourhood receives the packet and removes its information row from the Table 1.

Figure 1 shows the flowchart of this phase.

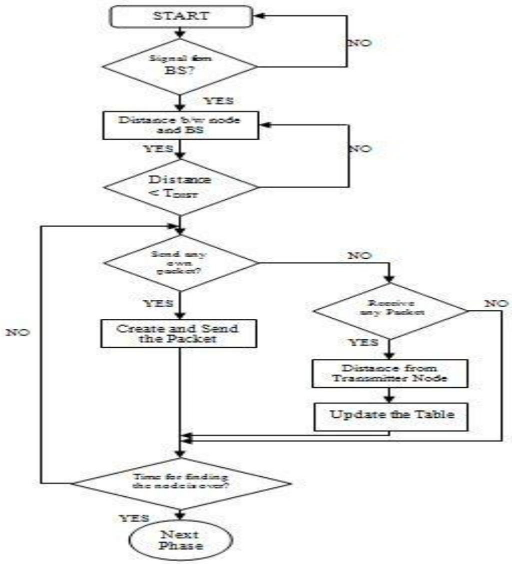

Fig. 1: Phase A- Finding All the Nodes

3.2. Phase B: Cluster Head Selection

In this phase all of the node in a cluster should have to calculate its own weight as using the equation:

$$W = \alpha.AD + \beta.OD + \gamma.T_{CH} - \varphi.\ E_{RESU} / E_{INIT}$$
$$0 \leq \alpha, \beta, \gamma$$
$$\varphi \leq 1$$

Where α, β, γ and φ are adjusting coefficients, T_{CH} is the times that the node has been a CH so far, E_{RESU} is the residual energy, E_{INIT} is initial energy, AD is average distance to neighbors and OD is the optimum deviation. AD can be calculated as follows:

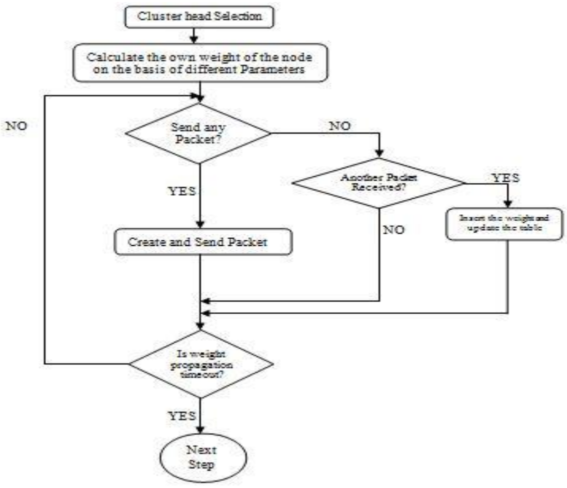

Fig. 2: Phase B – Cluster Head Selection Step 1

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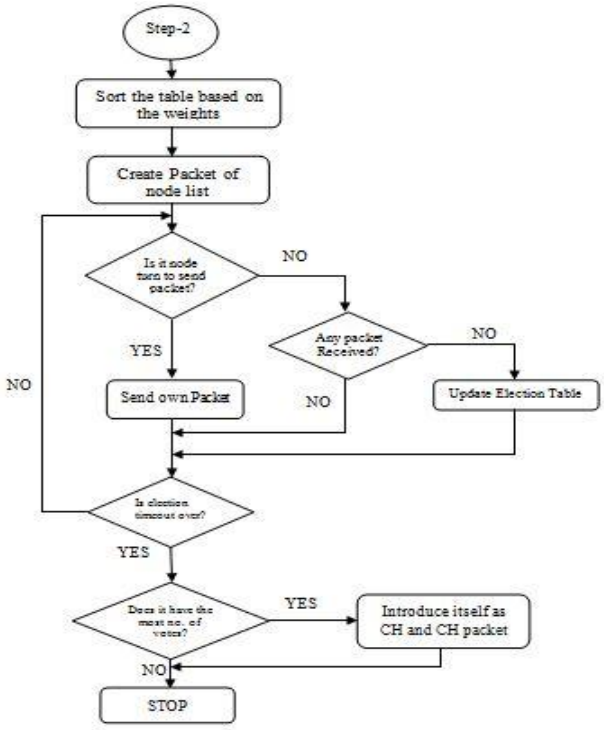

Fig. 3: Phase B – Cluster Head Selection Step 2

3.3. Phase C: Cluster Generating

As discussed before, the CH introduces itself by sending a packet to its neighbors. All nodes in its radio range hear the packets and are aware of the voting result, so when they receive the CH-Packet they respond by sending a packet to the CH (Join-Packet). The CH accepts their join request based on their weight from less to greater. In other words, the NO accepted nodes in cluster are the NO lower nodes in the weight-sorted table. The reason for priority voting is that often, after primary clustering, there are some nodes that are not in any cluster, because of the limited size of clusters, so in a second step, the nodes which have the highest vote and were not elected in the previous step introduce themselves as CH and the previous process will repeat. Finally, if there is a node which is neither organized nor received any packets, it introduces itself as a CH (outlying nodes).

The benefit of this iterative method is that we don't have overlapping clusters. For example when node Y becomes a CH in a specific region it certainly has received the highest number of votes, which means that all neighbor nodes know Y as the most weighted node. The elected CH forms a cluster and accepts nearby nodes into its cluster. Also in some regions where the density of nodes is high and the cluster size is limited, the cluster is filled and some nodes will not be organized.

In this case according to weight-based acceptance, the remaining nodes are the high weighted nodes of the previous step. These nodes elect the most weighted node among themselves as CH.

IV. CONCLUSION

This paper has proposed new distributed optimization clustering technique ideas for Wireless Sensor Networks called the DOCT protocol. The DOCT method is an energy-efficient, scalable, load-balanced and self-organized clustering protocol that could be employed in large-scale and harsh environments. The size of clusters vary depending on the distances from the data link to overcome the energy hole problem for nodes closer to the base station. The results confirmed that DOCT prolongs the network lifetime for both evenly and random sensor node distributions compared to some well-known clustering protocols in the literature such as the LEACH, HEED, WCA, GCMRA and TCAC protocols.

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