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Energy Saving Clustering Algorithms for Wireless Sensor Networks

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Abstract— A web of sensor nodes consisting of randomly distributed devices, used to monitor physical or environmental conditions is termed as a wireless sensor network. Sensor nodes discover, store, analyze, and transmit the data from the surroundings to the base station. Transmission of packets is the most crucial task for the networks among all the tasks of a sensor node. But transmission of data consumes energy in major proportion [1] and thus affects the life-span of the whole network, so routing in WSN should be energy efficient. A lot of research efforts have been put to design clustering algorithm that perform efficiently in increasing the energy efficiency in WSN. This paper gives an overview of the different routing energy saving clustering algorithms used in wireless sensor networks.
Keywords— DEEC, HEED, LEACH, REAC-IN, WSN

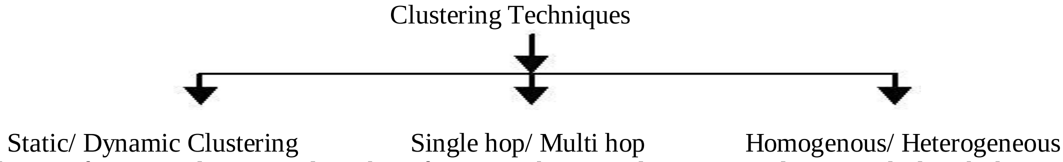
I. Introduction

As WSNs are considered powerful tools in monitoring physical or environmental conditions, research have densely explored in the field of WSNs related to durability, seamless communication, reliability and security. Among all these, the energy efficiency of WSNs is the most scorching and hence has attracted a lot of attention. Direct communication of data from each sensor node to sink consumes a lot of energy. Therefore, there is a need of splitting the region in small units and then combine the output of different units to serve as one, this process of splitting the region in WSNs is termed as clustering. Transmission and processing of data in each group is handled by the head of that group known as cluster head and then the processed data is transmitted from each group to the base station, which is then further processed and combined for the end user. Numerous clustering algorithms have been put forward in the last decade to process the data present in sensor networks in the most efficient way.
The section II in this paper briefs the various types of clustering algorithms for WSNs and section III describes the existing clustering algorithms for WSNs and the last section concludes our paper with the future direction in WSN.

II. ROUTING STRATEGIES IN WSN

A variety of clustering techniques have been proposed for the WSNs till today. Clustering is based on certain parameters like distance, proximity or logical organization. So, the sensors that are clustered together vary among themselves based on these factors.

The clustering techniques differ from each other on following criteria's [5, 6]:



The evolution of various clustering algorithms for WSNs has raised a great revolution to deal with the issue of lifetime. By using clustering, number of nodes participating in data transmission is reduced as aggregated data is sent to the base station. The energy consumption is reduced because of less participation of nodes in transmission of data. Thus the communication overhead is overall getting reduced.

A. Dynamic and Static Clustering

In the process of *dynamic clustering,* cluster organization is followed by cluster head election. Dynamic clustering consists of two steps and these steps are further parted into two phases:

1) The setup phase and,
2) The steady-state phase

Setup phase, being the first phase of every step, involves the formation of clusters and is proceeded by cluster head selection. The steady-state phase makes the cluster head gather data from the non cluster head nodes and transmits it to the base station.

Static clustering is split into steps, where each step contains only the steady-state phase. Each step allows the cluster head to collect data and battery status from non cluster head nodes. The received data is then processed and sent to the base station, new cluster heads are formed on the basis of the battery status so received.[5]

B. Single Hop and Multi Hop Clustering

A segment of the course from source to destination is termed as a hop. The count of intermediate devices through which the packet is transmitted from source to destination is referred to as hop count.

The network that allows direct communication between the source and the destination (commonly referred as sensor nodes and cluster heads) is said to be a *single hop network*.

A network that does not allows direct communication between source and destination, thus seek help of intermediate nodes is said to be a *multi-hop network*. In both of the above cases, the cluster heads transmits the data to the base station in a single hop.

C. Homogeneous and Heterogeneous Clustering

A network consisting of identical nodes in respect of battery and hardware complexity is called a *homogeneous sensor network*.

A *heterogeneous sensor* network consists of variety of nodes in respect of battery level and functionality.

III. Widely Used Clustering Algorithms

Younis *et al.* [4] says, the vital function in clustering algorithms is to select a group of cluster heads from the randomly deployed nodes in the network and then organizing the cluster accordingly. Custer heads look after the coordination among nodes of their respective clusters, collection and transmission of the data received from nodes (intra cluster coordination), and lastly communicate with each other and/or with base station (inter cluster communication).

A. *Low- Energy Adaptive Clustering Hierarchy (LEACH)*

LEACH [1] uses the concept of clustering principle where the energy consumption among the sensor nodes is distributed randomly. LEACH is disintegrated into rounds; each round embarks with set-up phase, allowing the election of cluster heads, pursued by steady-state phase, where data is transmitted to base station. LEACH is divided into the following steps:

Advertisement phase: In the first step of LEACH protocol, each node decides on its own whether or not to become a cluster head, a number n is chose between 0 and 1 to make this decision. A node turns out to be a cluster head for that round, if n is less than a threshold T(n), where T(n) is computed as [1]:

$$T(n) = \begin{cases} \frac{p}{p-1} * \left(r * \text{mod} \frac{1}{p}\right) \text{ if } n \in S \\ 0 \qquad\qquad\qquad\qquad , \text{otherwise} \end{cases} \qquad (1)$$

A notification is sent by the cluster head to all the nodes within its range to become a part of the cluster, acceptance of the offer is based upon the received signal strength.

Cluster set-up step: An acknowledgement is sent by the nodes to the cluster heads.

Schedule generation: The cluster heads generate a schedule based on time division multiple access after receiving response from nodes. The schedule is then broadcasted to the members of the clusters, informing them about the time when they can transmit.

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Data transmission: After receiving the entire data, signal processing functions are performed by the cluster head for the compression of data; the data is then sent to the base station.

In the LEACH protocol multi cluster interference problem, which occurs in the data transmission phase where exchange of data between two nodes can corrupt the data transmission of third node, is resolved by using unique code division multiple access codes for each cluster. The fused data is finally sent by each cluster head to the base station. LEACH outperforms static clustering algorithm [1] and has shown a considerable improvement by minimizing the global energy consumption as it distributes the load to all the nodes and also LEACH does not demands the whole knowledge of the network from the nodes.

B. *Hybrid Energy-Efficient Distributed Clustering (HEED)*

Energy efficiency is the factor that proves LEACH a better algorithm than its predecessors, but its limitation lies in the random cluster head selection. The worst case may have uneven distribution of cluster heads, effecting the collection of data. Hybrid Energy-Efficient Distributed (HEED) was evolved so as to avoid the random cluster head election. In HEED, cluster heads are elected on the basis of communication cost and remaining energy state. The four major goals of this algorithm are:

a) Extending the network lifespan with the help of distributing energy utilization,

b) Aborting clustering operation in fixed number of iterations,

c) Reducing control overload,

d) Providing appropriate distributed cluster heads and compact clusters.

The phases involved in HEED are:

Initialization phase: Here, the percentage of initial head nodes is set amongst all nodes, C_{prob}. The probability of becoming a cluster head is calculated by each sensor node as, [2],

$$CH_{prob} = C_{prob} \times \frac{E_{residual}}{E_{max}} \qquad (2)$$

Where $E_{residual}$ is the remaining energy level of the referred node; E_{max} is the utmost energy level of the node. E_{max} may fluctuate based on the functionality and capacity of a node as HEED encourages heterogeneity in the sensor networks.

Repetition phase: The cluster head hunt stops when a node with high remaining energy and least transmission cost is found.

Finalization phase: The tentative cluster head is finalized as the cluster head here.

In HEED, the problem of random selection of node is eliminated [2] and it proves to be better than the previously developed algorithm [1] as it utilizes the availability of multiple transmission power levels at sensor nodes, minimizes the communication cost, and prolongs the lifetime.

C. *Distributed Energy-Efficient Clustering (DEEC)*

The biggest drawback of the previously developed algorithms is that they are homogeneous clustering algorithms (although HEED supports two-stage heterogeneous WSN, but it does not work systematically in multi-level network). So to overcome this drawback a multi-level heterogeneous clustering algorithm is recommended which is titled as Distributed Energy-Efficient Clustering (DEEC). In DEEC, selection of cluster heads depends on the inceptive and remaining energy of the nodes. To circumvent that every individual node needs to know the entire information of the network at every cluster head selection round, absolute value of the network's duration is evaluated by DEEC and then used to calculate associated energy that every node must have for expansion during a round [3]. Let us look at the working of DEEC protocol.

Cluster head selection: In DEEC, the frequency of being a cluster head can be different for all nodes, as each possesses different properties in a heterogeneous clustering algorithm; it depends on the remaining energy of the node and the central value of the energy in the network after every round [3]. Each node uses the probability threshold to determine if it is capable of becoming a cluster head or not. Probability of a node with high residual energy to be a cluster head is more than the node with low residual energy.

Estimating average energy of the network: The central value of energy is used as the referral energy for every node. It is the absolute energy that every node is supposed to have in that round so that the network can remain awake for a long time. In this scenario, each and every node dies at the same time because energy is evenly distributed among the nodes and also in the network. It implies that each node is consuming equivalent amount of energy during each round, which is desirable and also targeted by energy-saving algorithms.

DEEC proves to achieve a longer lifetime than the already developed clustering algorithms [1, 2] as it use mean energy of the network as the referral energy and it also performs well in multi-level heterogeneous networks.

D. *Regional Energy Aware Clustering with Isolated Nodes (REAC-IN)*

In bigger networks, the total energy of the network is not capable enough to represent the situation of the entire network, and this put limit on DEEC, as it involves overhead in computing the mean energy of the network. So, to overcome this problem REAC-IN considers the regional (local) mean energy of the network to extend the lifespan of WSNs.
The another problem that REAC-IN resolves is excess energy consumption by isolated nodes in establishing communication with the sink in poor clustering algorithms, in the worst case where the distance is fairly far, this can be hazardous to deplete its energy, resulting in a fragmented sensing coverage. The steps involved in REAC-IN are:

Cluster Head Selection: REAC-IN uses the remaining energy and regional average energy of all the sensors in every cluster to select the cluster heads. A node decides of being a cluster head on the basis of probability threshold, which is calculated using [3],

$$T(n) = \begin{cases} \frac{p\mathrm{i}}{p\mathrm{i}-1} * \left(r * mod \frac{1}{p\mathrm{i}}\right) \; if \; n \in S \\ 0 \qquad\qquad\qquad , otherwise \end{cases} \qquad (3)$$

Here p_i is the probability of a node n_i being elected as a cluster head in the round r, which is calculated using the desired percentage of cluster heads, remaining energy of the network and the regional average energy of the network.

Advertisement Phase: This phase is adapted from LEACH, where join-request is sent to every node by selected cluster heads. When this message is received by non-cluster heads, they choose the nearest cluster head and those nodes which do not received any join-request is termed as isolated nodes. The determination of data transmission by isolated nodes is done considering the previous and current situation.
An isolated node will send its observed data directly to the sink, if [4]:

1) $E_i(r) >= \overline{E}_{c,i}(r - 1)$, and (4)
2) $D^2_{i,s} < (D^2_{i,\mu} + D^2_{\mu,s})$ (5)

Otherwise, the isolated node sends its data to the cluster head, with which it was associated in the previous round, which is also referred to as relay node µ.

Leu *et al.* [4] says,

1) REAC-IN extends the lifetime of the network up to 40%.
2) Larger amount of data is received at sink in REAC-IN, as compared to LEACH, HEED and DEEC.
3)

Decrement in the number of isolated nodes promotes prolonged network lifetime.

TABLE I
PARAMETERS USED IN REAC-IN [4]

Parameter	**Definition**
μ	the cluster head node in the previous round
i	the current node
s	the sink node
$D^2_{i,\mu}$	the distance between i and μ
$D^2_{\mu,s}$	the distance μ and s
$D^2_{i,s}$	the distance between i and s
$E_i(r)$	the residual energy of i
$\overline{E}_{c,i}(r - 1)$	the regional average energy of the cluster c where i belongs to at the round r - 1

TABLE II
COMPARISON TABLE OF CLUSTERING ALGORITHMS

Clustering Algorithm	**Cluster head selection approach**	**Amount of data received**	**Average lifetime**	**Problems Solved**
LEACH	Initial energy/ random approach	Least	Least	Network Lifetime and Multi-cluster interference problem
HEED	Residual Energy	More than LEACH	More than LEACH	Problem of random cluster head selection
DEEC	Initial Energy and Residual Energy	More than HEED	More than HEED	Multi-level Heterogeneous Network
REAC-IN	Residual and Regional Average Energy	More than DEEC	More than DEEC	Isolated nodes

IV. CONCLUSION AND FUTURE SCOPE

Wireless sensor networks have wide space of applications in smart homes, military, health, surveillance, security etc. So network should be energy efficient to deliver their precise functioning. Due to fixed energy of nodes, clustering of nodes is necessary to facilitate scalability, energy efficiency and extended network life and researchers have found that clustering is one of the promising method to achieve the goal of enhancing the lifetime of a wireless sensor network and hence the researchers have developed different clustering methods to get optimal clusters, cluster head selection. In future, we are thinking to propose and simulate a new protocol based on heterogeneous networks by combining the advantages of REAC-IN.

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