Cluster Head Selection Mechanisms in Homogeneous and Heterogeneous WSNs: A Survey

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Abstract- Wireless Sensor Networks are energy constrained networks that are deployed to sense an environment. The battery of the nodes in these networks depletes with the network operational time and eventually the nodes die out of battery. It becomes very important to minimize the energy consumption in these networks as it is nearly impossible to replace the battery of the dead nodes. Energy consumption can be reduced by employing clustering techniques. The crux of any clustering approach is the cluster head selection mechanism. This paper briefly surveys the cluster head selection techniques used in both homogeneous and heterogeneous WSNs.

Keywords-Wireless Sensor Networks, Clustering, Cluster head

I. INTRODUCTION

Wireless Sensor Networks (WSNs) [1] came into existence due to the advances in wireless communications, digital electronics and micro-electro-mechanical systems technologies. These networks differ from the traditional networks and provide with distributed computation, communication and sensing. In order to sense an environment these networks are either deployed randomly or in a preplanned manner both in attended and unattended modes. Some of the applications [2] of these networks include industrial automation, military surveillance, monitoring patients in hospitals, managing inventory, environmental monitoring, vehicle tracking, etc.

WSNs are networks with constraints of memory, energy, computation and communication. The hardest of all these constraints is the battery constraint. This is because once the node dies out of battery then it becomes impossible to replace it if the network is deployed in unattended environments. Hence to keep the network operational it is desired to reduce energy consumption in the network. Other features [3] of these networks include dynamic topology, self organization capabilities, lack of unique global identification for nodes, dense deployment, frequent node failures, node heterogeneity, etc.

It has been observed that the energy consumed in communication of data is far greater than the energy required for computation. In order to save energy in networks, it is advised to minimize the amount of data that needs to be communicated and route data to base station (BS) in an energy efficient manner. This phenomenon can be achieved through clustering mechanisms.

In clustering approaches, nearby sensor nodes are organized into groups called clusters. A representative node of each of the group is selected which is known as Cluster Head (CH). The CH is responsible for intracluster and intercluster communication, data aggregation, etc. The cluster members sense the data and send this data to the CH. The CH then aggregates the data by applying suitable aggregation function like mean, median, etc. and sends this data to the BS.

There exists many research works on clustering techniques both in homogeneous and heterogeneous environments. The central point of any clustering scheme is the criteria used for CH selection. The CHs perform many operations thereby consuming a lot of their energy. Hence suitable nodes must be selected as CHs so as to keep the network functional. The CHs are selected based on factors like residual energy, connectivity, communication cost, etc. In this paper a survey on CH selection criteria both in homogeneous and heterogeneous environments is presented.

The paper is organized as follows: Section II gives details of clustering approach with their advantages and some of the issues. Section III presents CH selection criteria in various protocols for homogeneous WSNs followed by section IV that describes the CH selection criteria for heterogeneous WSNs. Section V concludes the paper.

II. CLUSTERING & ITS ISSUES

In clustering, nodes are organized into virtual groups with a leader node known as cluster head. The CH collects data from its member nodes, aggregates it and sends it to the BS. Figure 1 explains the clustering approach.

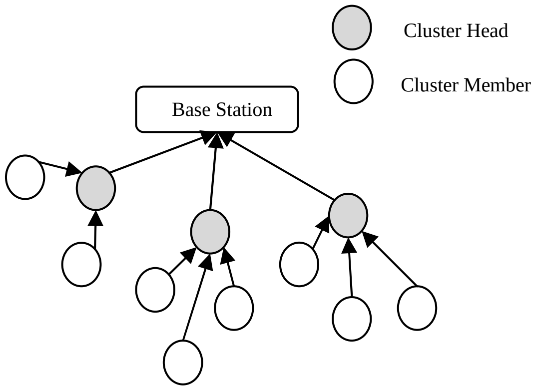

Fig. 1: Clustering mechanism

Grouping of nodes into virtual groups increases network lifetime and balances load. It also increases the scalability of the system and reduces collisions in the network. Further, it decreases the size of the routing table that needs to be maintained at each of the nodes.

For selecting a set of CHs in the network there are several points [4] that need to be considered like:

- Whether the CHs are evenly distributed in the network
- Whether the selected CH set ensures load distribution
- Which sensor nodes must be selected as the CHs
- What is the deciding criteria for CH selection
- How are CHs selected

III. CLUSTER HEAD SELECTION IN HOMOGENEOUS WSNS

Nodes in homogeneous WSNs have similar capabilities. These have the same amount of computation and communication power, the same amount of memory and battery. The CH selection criteria in these nodes is based on factors like node's residual energy, the number of times the node has become CH, connectivity degree, average distance of a node from its cluster members, etc. The following section explains some of the techniques employed in the selection of CH in homogeneous WSNs.

Heizalman et al. [5] proposed Low Energy Adaptive Clustering Hierarchy (LEACH). The CHs are selected based on the required percentage of CHs for the network and also on the number of times the node has become CH. Each node generated a random number which was then compared with a threshold value given by:

$$T(n) = \begin{cases} \dfrac{p}{1 - p * (r \bmod 1/p)} & , \ if\ n \in G \\ 0 & , otherwise \end{cases} \qquad (1)$$

where n is the node, p is the desired percentage of CHs needed in the network, r is the current round and G is the set of nodes that had not been CH in last 1/p rounds.

The Hybrid Energy Efficient Clustering (HEED) proposed by Younis et al. [6] selects CH based on two parameters: the primary parameter as the residual energy of the node and secondary parameter as the communication cost. The communication cost is calculated using the average minimum reachability power or the node degree.

Rana et al. [7] presented a CH selection scheme using genetic algorithms. The fitness value is calculated using two parameters: the total distance as per cluster head selection so as to minimize energy consumption and the number of weak nodes. The total distance is defined as the distance of each node from its CH plus the distance of each CH to the BS. The weak nodes are defined as the nodes whose energy level goes below a certain level of threshold. The CH is selected so that the weak nodes and total distance is minimized.

Another technique was proposed by Lee et al. [8] that used the neighborhood degree fitness value and the residual energy fitness value of the nodes for the CH selection. The nodes with high residual energy and neighboring nodes have greater chances to become CH. The fitness value for a node is given by sum of the energy state fitness value and neighborhood fitness value. The neighborhood fitness value is given by:

$$= (1 + \frac{number\ of\ neighbor\ of\ n}{max.number\ of\ neighbor\ in\ cluster})^{\alpha} \quad (2)$$

And the energy state fitness value by:

$$= (1 + \frac{residual\ energy\ of\ n}{max.residual\ energy\ of\ cluster})^{1-\alpha} \quad (3)$$

The total fitness value is adjusted using α. The value of α is kept more in the beginning of networking. This is because residual energy of all nodes is almost the same and thus the important factor in decision of the CH selection remains the number of neighbors while in the later period the residual energy becomes important and α is adjusted accordingly.

Zhao et al. [9] proposed improved LEACH that reduces the frequency of reclustering which saves the energy of the network. Apart from CHs, it selects Vice CHs (VCHs) for each cluster that take the role of CH in later phase of steady state which reduces the need of reclustering. The threshold value for a node n is given by:

$$T(n) = \begin{cases} \frac{p}{1 - p * (r\ mod\ 1/p)} * \left[\frac{E_{resi}}{E_{init}} + \left(1 - \frac{E_{resi}}{E_{init}}\right) * \frac{p}{CH_{times} + VCH_{times} + 1}\right], n \in G \\ 0 \qquad otherwise \end{cases} \quad (4)$$

where p is the desired percentage of CHs, r is the current round, E_{resi} is the residual energy of node, E_{init} is the initial energy of node, CH_{times} and VCH_{times} is the number of times the node n has become CH and VCH respectively. More is the residual energy and less is the number of times the node has become CH and VCH, the more are the chances for a node to be elected as CH.

A Coverage-preserving Energy-based Clustering algorithm (CEC) is presented by Di [10] that takes both the residual energy and the coverage rate as factors for CH selection. The threshold value is modified to:

$$T(n) = \begin{cases} \frac{p}{1 - p * (r\ mod\ 1/p)} * p_n^{energy} * p_n^{coverage}, n \in G \\ 0 \qquad , otherwise \end{cases} \quad (5)$$

where the first factor is the ratio of node's residual energy to the average residual energy, and the second is the ratio of node's overlapping coverage rate to the node's neighbor average overlapping coverage rate.

A mechanism presented by Yong et al. [11] considered the ratio of residual energy of the node to the distance of the node with all other nodes in the same cluster as the threshold value to select the CHs. Another protocol proposed by Liu et al. [12] improved the threshold equation to:

$$T(n) = \begin{cases} \frac{p}{1 - p * (r\ mod\ 1/p)} * \frac{[E(n) + (1 - D(n))]}{2}, n \in G \\ 0 \qquad , otherwise \end{cases} \quad (6)$$

where E(n) is the ratio of residual energy of node to the initial energy, D(n) is the ratio of distance of node to BS and the maximum distance to BS, p, G and r are same as (1). The more is the energy of node and the less is the distance of node from BS, the more are the chances for a node to become CH. The proposed solution was used so that there are more number of CHs near to the BS and hence prevent the hot spot problem. Some of the other methods are studied in [13-15].

IV. CLUSTER HEAD SELECTION IN HETEROGENEOUS WSNS

Heterogeneous WSNs are networks where nodes are equipped with different capabilities. The heterogeneity of nodes can be classified into three types [16]: link heterogeneity, energy heterogeneity and computational heterogeneity. A node possesses link heterogeneity if it has high bandwidth and long-distance network transceiver than normal node; it possesses energy heterogeneity if it has high energy than normal nodes; and has computational heterogeneity if it has high processing capabilities than normal nodes. The heterogeneity in the nodes provide with improved throughput, low latency, high reliability, etc.

The CH selection in Heterogeneous WSNs is similar to the homogeneous case. The selection parameters include residual energy of nodes, initial energy of nodes, the fraction of nodes that are equipped with more energy than normal nodes, energy consumption rate of nodes, etc. In this section we consider energy heterogeneous nodes and discuss the techniques for CH selection.

Stable Election Protocol (SEP) proposed by Smaradakis et al. [17] consisted of two level of heterogeneity: normal nodes and advanced nodes. The advanced nodes have higher energy than the normal nodes. The probability of nodes to become CH is based on the initial energy of the node to that of other nodes in the network. A similar protocol proposed by Kumar et al. [18] extends the network to have three levels of heterogeneous nodes: normal, advanced and super nodes.

Qing et al. [19] presented a CH selection mechanism where the probabilities of the nodes were based on the initial energy of the nodes with respect to other nodes in the network and the residual energy of the node to the average energy of the network. Siani et al. [20] presented a similar technique but with three level of heterogeneity while Quereshi e al. [21] extended it to four levels of heterogeneous nodes.

Enhanced Developed Distributed Energy Efficient Clustering (EDDEEC) [22] changed dynamically the CH selection probabilities based on a threshold value. Initially, all the three types of nodes have different election probabilities based on the residual energy and initial energy. But after a threshold value, the election probabilities of all the types of node become same. The threshold value is the value of residual energy level where all the normal, advanced and super nodes have same amount of energy left.

The work proposed by Xiaoya et al. [23] considers two types of nodes with same initial energy but different energy consumption rate. Nodes with more residual energy and least energy consumption rate are elected as CHs. The probability is calculated as:

$$p_{i=}\frac{{E_i}^{\propto}}{{v_i}^{\beta}} \qquad (7)$$

where E_i represents the residual energy of node, v_i is the energy consumption rate, α and β are optional parameters. Other schemes are discussed in [24-25].

V. CONCLUSION

Clustering in WSN reduces the energy consumption in the network and increases the network lifetime. The main motive of any clustering scheme is the optimal cluster head selection. The cluster heads are selected based on parameters like residual energy of node, node degree, cluster distance, initial energy of nodes, fraction of high energy nodes, energy consumption rate, etc. In this paper several cluster head selection schemes had been discussed.

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