A Novel Game Theoretic Approach for Cluster Head Selection in WSN

Sudakshina Dasgupta, Paramartha Dutta

Abstract*— In recent years wireless sensor network (WSN) is an active domain of research. A WSN consists of a number of sensor nodes each with limited energy, bandwidth, storage and processing capabilities. Clustering is one of the basic approaches that offer a practical way of providing scalability when designing a large and dense sensor networks. One of the approaches to enhance the survivability of WSN is to allow only some sensor nodes in a cluster of sensor nodes, called cluster heads, to communicate with the base station. In this paper we have proposed a Game theoretic approach for selecting a cluster head for every cluster in a WSN. Games can be a single round or repetitive. The scope a player enjoys in making his or her moves constitutes the player's "strategy". Rules govern the outcome for the set of moves taken by the players and outcomes produce payoffs for the various players which can be expressed by means of a payoff matrix. However, the clustering problem in wireless sensor network, related to self-organization of nodes into large groups and selection of head, has not been studied under this framework. In this work, our goal is to provide a game theoretical modeling of cluster-head selection for wireless sensor networks. A game of scheduling of nodes for taking the responsibility of cluster head, is an interactive decision making process between a set of self-interested nodes.

Index Terms— **Game Theory, payoff, clustering, Wireless sensor network, Cluster head.**

I. INTRODUCTION

A WSN [21] is composed of a number of wireless sensor nodes which form a sensor field and a sink. These large number of nodes with low-cost, low-power, and capable of communication at short distances perform limited computation and communicate wirelessly form the WSNs. Specific functions such as sensing, tracking and alerting can be obtained through cooperation among these nodes [24]. These functions make wireless sensors very useful for monitoring natural phenomena, environmental changes, controlling security, estimating traffic flows, monitoring military application, and tracking friendly forces in the battlefields [5], [6]. In order to support data aggregation through efficient network organization: wireless sensor network can be divided into several clusters. Each cluster has a number of sensor nodes and one of the nodes is elected as the coordinator, termed as head.

The head is responsible for not the general mission but also collecting the sensed data of other nodes and routing to the sink. Accordingly, its energy-consumption is higher than other nodes. Therefore, the head selection will affect the life-time of a network [7], [17], [27].

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A sensor network can be made scalable by assembling the sensor nodes into groups i.e. clusters. Every cluster has a leader, often referred to as the cluster-head (CH). A CH may be selected by the sensors in a cluster or preassigned by the network designer. The cluster membership may be fixed or variable. Number of clustering algorithms has been specifically designed for WSNs for scalability and efficient communication [6], [12]. In a hierarchical architecture, higher energy nodes (cluster heads) can be used to process and send the information while low energy nodes can be used to perform the sensing.

Game theory has been used for long periods in the field of science to mathematically determine optimal strategies in situations in which a competition between adversaries is taking place [17]. Game theory is a branch of applied mathematics. Its fundamental assumption is that players go after some certain aim and forecast other players actions by their knowledge [15]. Most applications of game theory involve in the areas of decision making, management, economics and finance. However, a few scholars and researchers began to pay attention to the application of game theory in Wireless Sensor network.

The selection of Cluster Heads in the WSN is a challenging issue as efficient cluster head selection algorithm can improve the lifetime of the network and can reduce the communication overhead in the network.

In our work we have considered the single-hop cluster-based WSN with hundreds or thousands sensor nodes dispersed in a field. Base Station (BS), an observer, is located outside the field remotely. The observed field is composed of several clusters. Each cluster has one CH which acts as a local control centre to coordinate the data transmissions. Here we have proposed a Game oriented algorithm to find the cluster heads. A game of scheduling of nodes for taking responsibility of cluster head, is an interactive decision making process among a set of self-interested nodes.

The node or the entities (decision makers) that play the game are called players. The players take part to the game by performing particular actions or moves. Each player has preferences for the action profiles. A player is affected not only by its own actions but also by the actions of the other players as well [13]. At the beginning of the game, it is assumed that the nodes transmit with maximum residual energy to gather information.

Rest of the paper is organized as follows. Section 2 describes the relevant work. In section 3 we present our Game theoretical approach for selection of cluster head in WSN. Section 4 contains the experimental result and section 5 describes the conclusion of this work.

II. RELATED WORK

In recent years, many algorithms and protocols for cluster head selection have been proposed [19], [22]. These algorithms improve the performance of cluster-head selection from different perspectives [23], [25]. In this section, we detail the related work on these improvements. The most well-known is the Low-Energy Adaptive Clustering Hierarchy (LEACH) [27] algorithm. According to this protocol, the role of the cluster head is not permanently assigned to particular nodes [24]. Each sensor is randomly self-elected as cluster head but it is ensured that all nodes will play this role within a predefined time interval. There are a number of cluster-head selection algorithms based on LEACH's architecture. A centralized version of LEACH, called LEACH-C uses a centralized controller to select Cluster heads (CH). By using a central control algorithm to form the clusters, it can produce better clusters by dispersing the CH nodes throughout the network. The results show that LEACH-C increases the network lifetime due to global knowledge and the ability to ensure that the optimum number of cluster heads is selected in each iteration [20]. The main drawbacks of this algorithm are non-automatic cluster-head selection and the requirement that the position of all sensors must be known beforehand. With a deterministic cluster head selection, that utilizes the remaining energy level of each node to determine the threshold in order to decide whether or not the cluster head should be rotated. However, to get the energy level of sensors in a real network usually needs a routing protocol which will create new cost. HEED (Hybrid Energy-Efficient Distributed Clustering) is a distributed clustering scheme in which CH nodes are picked from the deployed sensors [19]. HEED considers a hybrid of energy and communication cost while selecting Cluster Head. HEED makes no assumption regarding the location knowledge and it is completely distributed. Cluster Heads are randomly selected on the basis of their residual energy, it can be combined with a metric that takes the node density into account.

Mean Shift is a powerful and versatile non parametric iterative algorithm that can be used for lot of purposes like finding modes, clustering etc. Mean Shift was introduced by Fukunaga and Hostetler and has been extended for application in field like computer vision [14], [28]. Mean Shift considers feature space as an empirical probability density function. If dense regions or clusters are present in the feature space, then they correspond to the mode (or local maxima) of the probability density function. For each data point, Mean Shift associates it with the nearby peak of the data set's probability density function. For each data point, Mean Shift defines a window around it and computes the mean of the data point. Then it shifts the centre of the window to the mean and repeats the algorithm till it converges. After each iteration, we can consider that the window shifts to a denser region of the data set.

In CEFL (Cluster-head Election Using Fuzzy Logic) algorithm, fuzzy logic method is adopted to select the CH. Most of these clustering methods rely on synchronous clocking for exchanging information among sensors [8], [18].

The proposed algorithm focuses on improving the cluster-head selection method by game playing strategy to calculate the payoff matrix in a cluster with maximum residual energy in order to enhance the network lifetime.

III. PROPOSED WORK

The existing Cluster Head selection algorithms like LEACH does not consider the remaining energy of the sensor nodes for selection of the cluster head. Secondly they require the cluster heads be rotated in each round. This can lead to the wastage of the battery power of the nodes and can reduce the lifetime of the network.

In the proposed work we have considered the single-hop cluster-based WSN with hundreds of thousands sensor nodes dispersed in a field. Base Station (BS), an observer, is located outside the field remotely [9], [10], [11]. The observed field is composed of several clusters. Each cluster has one CH which acts as a local control centre to coordinate the data transmissions. Here we have proposed a Game based algorithm to find the cluster heads. The followings are the different selection parameters to select the cluster head for each cluster [4], [13].The major parameters [16], [26] to select cluster heads within the clusters are described below:

A. Distance factor: It is the distance between a node to all other nodes in that cluster
B. Internal energy: It is the remaining energy of a node after a number of packet transmission and reception by that node

Cluster head selection in the WSN is a NP-hard problem [1], [2] and hence a suitable optimization algorithm has been proposed to solve the problem. In the proposed work a Game theory based optimization algorithm has been designed to minimize the number of head nodes in the network.

Mathematical formulation

A game of scheduling of nodes for taking responsibility of cluster head, is an interactive decision making process between a set of self-interested nodes, which formally consists of the following elements.

A set of players N, which may be a group of nodes or one individual node in wireless Sensor networks in the proposed application. A set of actions are available for the player I to make a decision. The payoff vector $(u_1, u_2, \dots, u_n)$ are resulted from the strategy profile.

The node or the entities (decision makers) that play the game are called players. The players take part in the game by performing particular actions or moves. Each player has preferences for the action profiles. A player is affected not only by its own actions but also by the actions of the other players as well. At the beginning of the game, it is assumed that the nodes transmit with maximum residual energy to gather information [3]. We used radio energy dissipation model [12] to compute energy consumption. The energy used to transmit q bit of data at a distance d for each sensor node is:

$$ET_x(q, d) = qE_{Elec} + q\varepsilon f_s d^2 \qquad (1)$$

The energy used to receive data for each node is:

$$ER_x(q) = qE_{Elec} \qquad (2)$$

Where E_{Elec} is electronic energy and εf_s is power loss of free space. The depreciation of energy E_D of a node due to packet transmission is:

$$E_D = \alpha E_f + \beta E_r \qquad (3)$$

where E_f is the energy depreciation of forwarding a packet and E_r is the energy depreciation of receiving a packet and α is the rate of depreciation of packet forwarding and β is the rate of packet receiving. We can calculate the payoff using following formula:

$$payoff = (\alpha + \beta) \times ET_x(q,d) - E_D \quad (4)$$

where $(\alpha+\beta)ET_x(q,d)$ is the reward based on the usage in the network and E_D is penalty for depreciation of energy. The node having minimum payoff will be head of each cluster.

Proposed Cluster head selection Algorithm

In our work the single-hop cluster-based WSN with hundreds of sensor nodes by Fuzzy-c means algorithm [12] is to be found initially. Base station (BS), an observer, is located outside the field remotely. The observed field is composed of several clusters. Each cluster has one CH which acts as a local control centre to coordinate the data transmission .Here we have proposed a Game theoretic based approach to select the cluster heads. The algorithm can be described as follows:

Steps:

1. Read number of sensor node N in a defined area, say N=100.
2. Initialize residual energy of each node with 0.5 Jules and randomly deploy sensor nodes over a simulation area.
3. Apply Fuzzy-c means clustering approach to find initial clusters along with the member nodes.
   For each cluster and for each node member i
   a. Find the Euclidian distance from the base station to that node (we consider that nodes are not mobile).
   b. Compute energy consumption for each transmission sending and receiving by $ET_x(q,d)$ and $ER_x(q)$}.
4. Allow packet transmission in the network to the Base station and from one node of one cluster to the other node of another cluster through the Base station.
5. Find out the payoff of each node of each cluster by equation 3 and 4.
6. Maintain a table with a regular interval of t consisting of payoff and residual energy of every node of each cluster.
7. Now we calculate the total payoff of different node of each cluster as.
   $$payoff(C_i) = \sum_{i=1}^{n}(payoff) \quad (5)$$
   where C_i for all i over 1 through n many cluster given initially to the system.
8. For every time interval the total payoff can be calculated as $\sum$ payoff(C_i) and justify that which is in $1 \leq C_i \leq$ threshold and we can conclude that the system will stabilize with those elected head. In the proposed work threshold is the 5% of the initial energy.
9. Goto Step 2 When the total payoff of a cluster falls below the threshold value.
10. End.

Empirical analysis and Experimental result

We have analyzed the effect of different parameters like distance, number of packet transmission and receive over the calculation of payoff of the nodes competing to become the cluster head of the clusters. Figure 1 show that as the distance between the nodes that are randomly deployed in the network and the base station increases the payoff also increases. This is because the nodes nearer to the base station in the clusters are more suitable to become cluster heads. The graph in the figure in not perfectly linear because apart from the distance the other factors like number of packet transmission and receive by the nodes (which in turn affect the energy consumption of the nodes) also affects the payoff of the nodes.

Fig 1. Distance vs. Payoff

In order to explain the efficiency of the proposed algorithm, we have designed a simulation system to simulate our game theory based model in VC++. We have simulated over a 300x300 m^2 area with 100 sensor nodes deployed randomly over the simulation area. The initial node energy was considered as .5 Jules and mobility was disabled. The performance of the algorithm is compared with existing LEACH and HEED clustering algorithm. The payoff matrix plays a vital role in the Game playing approach to select the cluster heads in the network clusters and one can change the final game result only by changing the payoff matrix. At first the performance of the proposed algorithm is compared with the existing LEACH and HEED algorithms in terms of number of alive nodes over time. Both of the existing algorithms require cluster formation and re-clustering. In LEACH the cluster heads are rotated in each round, which is costly in terms of network lifetime. In HEED algorithm the residual energy of the nodes and optimal percentage of Cluster heads in each round is considered and hence it is better than the LEACH algorithm in terms of network lifetime. Figure 2 show that our proposed algorithm performs better than the existing LEACH and HEED algorithm in terms of number of nodes alive over time. In other words it improves the network lifetime of a wireless sensor network. Figure 3 shows that the proposed algorithm elects fewer cluster heads than HEED under the transmission range of 25 meter or even larger. The difference is more significant with relatively small transmission range and small number of rounds. It performs better in relatively sparse networks when the number of iteration is limited.

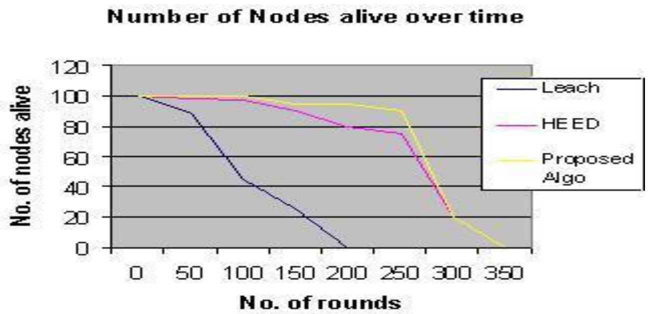

Fig 2. Number of alive nodes over time

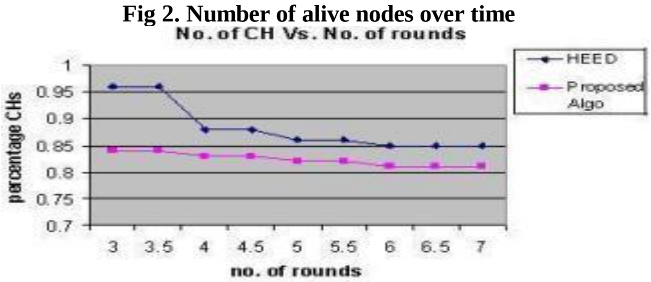

Fig 3. Number of CHs vs. Rounds

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IV. CONCLUSION

This work shows that our proposed game theoretic approach can be applied in the selection of cluster heads in the wireless sensor network. This approach is better than the existing LEACH and HEEDS algorithms in terms of network lifetime and optimal selection of cluster heads. The game parameters can be dynamically adjusted to calculate the new payoff matrix which in turn will affect the cluster head selection process.

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