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DISTRIBUTED CLUSTERING IN WIRELESS SENSOR NETWORKS USING A GAME THEORETICAL APPROACH

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Abstract- Wireless Sensor Networks (WSNs) consist of a large number of tiny and battery operated sensor nodes. Reducing energy consumption of sensor nodes and consequently prolonging the network lifetime with providing application-specific requirements is an important issue in WSNs. According to literature, clustered based routing protocols are one of the techniques for delivering data in an energy aware way in WSNs. Hence, in this paper, clustering of sensor nodes is modeled as a game and we utilized a game theoretical approach for prolonging network lifetime. Our proposed algorithm named Distributed Clustering by Game Theoretical approach (DCGT) considers parameters such as residual energy, distance to the base station, distance to neighbors and cost of being a cluster head for each sensor node to design a game table. Based on parameters in the DCGT, each node computes mixed strategies Nash equilibrium of game, which shows the probability of being the cluster, head. Simulation results prove the efficiency of the DCGT in prolonging network lifetime compare to the LEACH and another state of the art algorithm (CROSS).

Keywords: Clustering, Wireless Sensor Networks, Game Theory, Nash Equilibrium.

I. INTRODUCTION

Wireless sensor networks (WSNs) are very useful in many applications such as military and industrial control, home and health care delivery and environment surveillance [1]. Sensor nodes in WSNs do simple process on raw data and collaborate with each other to deliver data to the Base Station (BS). However, they have some limitations on processor, memory and communication components, and energy resource. According to the literature, in many applications sensor nodes are distributed in monitor harsh environments and disaster areas in many applications, therefore, battery replacement or recharge is not frugal and efficient energy consumption is one of the most important issues in WSNs.

Recently, energy aware mechanisms are considered to provide a long-lasting operation without the need for battery replacement [2]. Many research studies have been accomplished on this goal by using coding techniques in application layer, efficient methods for Medium Access Control (MAC) in data link layer, and energy efficient routing protocols in network layer [3]. We focus on routing protocols to provide energy efficiency in network layer.

Clustering methods are energy efficient forwarding methods to deliver data to the base station in applications with large number of sensor nodes [4]. In clustering, some sensor nodes are selected as the cluster heads to manage the cluster members, which are responsible for sending data to the cluster heads. The cluster heads aggregate data and send them to the base station.

Artificial intelligence techniques have been recently used for presenting network protocols [5]. Game Theory has been utilized for modeling load balancing [6], preventing the attacks [7], and detecting the intrusions [8] in networks. In this paper, we propose a distributed clustering game for prolonging network lifetime and increasing the network performance using the Game Theory. To achieve this goal, four parameters are considered (residual energy, the cost of being a cluster head, distance to the base station, and distance to neighbors for each sensor node), which have tremendous effects in selection of cluster heads.

These parameters are used for designing a game table and computing mixed strategy Nash equilibrium of the game. Simulation results prove the efficiency of our algorithm compared to the literature. The rest of the paper is organized as follows, section 2 is an overview of the related works in ad-hoc, and wireless sensor networks clustering algorithms. Section 3 describes the proposed algorithm, clustering game, computing Nash equilibrium of game and the phases of forwarding data to the base station. Section 4 evaluates and compares the DCGT with other clustering protocols. Finally, conclusion and future works are presented in section 5.

II. RELATED WORK

Based on literature, there are many centralized or distributed clustering algorithms for WSNs. In central algorithms, the task of cluster head selection is done by the base station like GABEEC [9], CCGA [10], ECPF [11], CFGA [12, 13]. In distributed algorithms, each sensor node based on its characteristics and application specific requirements decides to be a cluster head or not. Considering the extension of clustering issue in WSNs, in this paper, we focus only on the distributed clustering algorithms.

One of the most well-known and popular distributed algorithms is the Low-Energy Adaptive Clustering Hierarchy (LEACH) [14]. In this algorithm, each sensor node is randomly become a cluster head based on the considered probability function. It is worth mentioning that the roll of being cluster head rotate among all sensor nodes and consequently the energy consumption of sensor nodes is balanced.

Because of random selection of cluster heads in the LEACH, it is highly possible that some of the cluster heads be very close to each other. Therefore, the un-uniformly distribution of cluster heads in the monitored area is one of the main drawbacks of the LEACH. MECH [14] attempts to solve this problem by constructing clusters based on sensor nodes radio range and number of cluster members [15]. In [16], authors have extended the LEACH algorithm by considering current energy of sensor nodes in probability function to select proper cluster heads. This algorithm has shown a good performance in prolonging the network lifetime.

Another distributed clustering algorithm, HEED [17], selects cluster heads based on the residual energy of sensor nodes. Consequently, sensor nodes with more energy have more probability to become cluster head. Simulation results in [17] have shown that HEED uniformly distributed cluster heads in the monitored area besides prolonging the network lifetime. MRPUC [18] is an unequal clustering algorithm for WSNs. In this algorithm, each sensor node joins to cluster whose cluster head has more energy and less distance. In addition, clusters, which are closer to the base station are smaller than the others.

In [19], cluster based virtual MIMO technique is used for energy efficient communications, which prolong first node death time. Cluster heads selection is based on their available energy. Simulations show that MIMO (Two-In, Two-Out) is more energy efficient than SISO and other MIMO variations [19]. In [20], authors considered another distributed clustering algorithm called ARPEES. Energy efficiency, dynamic event clustering, and multi-hop clustering are main design features of ARPEES.

Initially, all sensor nodes are in sleep mode, after occurring an event, sensor nodes, which can detect event change their state to active mode and broadcast a control message to initiate process of selecting cluster heads. Then, each sensor node set its timer and when time expired, sensor nodes, which receive more messages and also have more energy become cluster head. Authors have shown that their proposed algorithm can reduce the energy consumption and increase network lifetime more than the LEACH and the other well-known clustering algorithms.

EACA [21] is another distributed clustering algorithm, which used residual energy of sensor nodes, and distance from the neighbors to selected the best cluster heads. Authors in [21] proposed multilevel distributed clustering algorithm that converts a flat network to a hierarchical structure. Simulation results demonstrate that the EACA reduce energy consumption compared to the LEACH algorithm. Recently game theory has been applied successfully as a distributed algorithm for WSNs clustering [22-24]. Game theory with its powerful mathematical basis can be used to find more efficient solutions in terms of energy consumption for WSNs clustering. We can refer to CROSS [24] algorithm, one of state of the art methods in the field, has used the same approach to tackle the problem. This algorithm models WSNs clustering as a game. Mixed strategy Nash Equilibrium of the game is computed to determine the probability of being cluster head for each sensor node.

This probability depends on the number of sensor nodes in the network and the cost of being a cluster head. Considering the importance of game theory in distributed WSNs clustering, our goal is to design a new game for clustering of sensor nodes with residual energy, cost of being a cluster head, distance to the base station, and distance to the neighbors for each sensor node as its parameters. We assume that the nodes in the network are the players of the game and each sensor node computes the probability of being a cluster head itself.

III. PROPOSED ALGORITHM

According to section 2, game theory is used for prolonging network lifetime and energy efficiency of sensor nodes and finally increases efficiency of network.

A. Clustering Game

The clustering game played by the sensor nodes in the network to select proper sensor nodes as cluster head that can gather data from its cluster members aggregate them and forward to the base station. Here, a game can be defined formally as $CGT = \langle N, S, U \rangle$, where N is the set of players the sensor nodes in the network, S is the set of available strategies that players can choose, and finally U is the set of utility functions. It is assumed that the N sensor nodes playing the game are uniformly distributed in the network environment.

Each node can choose one of the two possible strategies. If a node decides to become a cluster head, it chooses DCH, which means, 'declare itself as a cluster head'. Otherwise, it chooses the DO strategy, which means 'declare itself as an ordinary sensor node'. Payoff of the sensor nodes are computed as described below.

$$U_i(s) = \begin{cases} 0 & \text{if} \quad s_j \in DO, \ \forall j \in N \\ \Delta & \text{if} \quad s_i \in DCH \\ v & \text{if} \quad s_i \in DO \ \& \ \exists\, j \in N \quad \text{s.t.} \quad s_j = DCH \end{cases} \tag{1}$$

If a sensor node plays DO strategy and no other nodes choose to become a cluster head either, its payoff will be zero. In such a situation, there is no cluster head in the network, and hence the sensor nodes should send their data directly to the base station. If at least one neighbor of the player selects DCH strategy, then the payoff of that player will be equal to V, i.e. the gain in successfully delivering data to the base station. Finally, if the sensor node plays DCH strategy, its payoff will be $V + w_1E - w_2C - w_3H - w_4O$. Where, E is the residual energy of each sensor node, C is the cost of being a cluster head, H is the distance of sensor node to the base station, O is the distance of other neighbors to sensor node, and w_1, w_2, w_3, and w_4 are the weights computed for these parameters. The payoff table for the simple two players is shown in Table 1.

Table 1. The payoffs for the simple two sensor nodes

	DCH	*DO*
DCH	(Δ*, Δ)	(Δ, V)
DO	(V, Δ)	(0, 0)
*$\Delta = V + w_1E - w_2C - w_3H - w_4O$		

B. Probability of Being CH and Nash Equilibrium

To compute probability for each sensor node to decide being cluster head or not, the Nash equilibrium of clustering game should be found. According to Table 1, clearly the game is symmetrical so payoffs just depend on the strategies that players choose, not on the player. The (*DCH*, *DCH*) strategy is not a Nash equilibrium because players prefer to play the *DO* strategy which can gain more payoff ($V>\Delta$). For the same reason, (*DO*, *DO*) strategy also is not Nash equilibrium of this game, because the player prefers to play *DCH* strategy to gain much more payoff. If one player declares itself as cluster head and plays *DCH* strategy and the other one plays *DO* strategy, none of them wants to change their strategies.

Hence the (*DO*, *DCH*) and (*DCH*, *DO*) strategies are the Nash equilibrium of our game. Clearly, there is not any symmetrical Nash equilibrium in this game. To extend the game for N players, let $S = \{s_1, s_2, \ldots, s_N\}$ be the vector of the strategies followed by the players means that the first player chooses s_1 strategy, the second player chooses s_2 and so on. If all of the players play *DO* strategy, the payoff of all will be zero. If at least one player declares itself as cluster head, its payoff will be Δ and the payoff of all other players will be V.

Hence, the utility function $U_i(s)$ of player i can be obtained from the following equation. As mentioned before, this game does not have any symmetrical Nash equilibrium. To have symmetrical Nash equilibrium, the players are allowed to play mixed strategies. Hence, the players choose their strategies randomly following a probability distribution. It means that each sensor node has a probability to declare itself as cluster head. Let denote the probability of playing *DCH* strategy as p, so the probability of playing *DO* strategy is $q=1-p$.

Theorem 1: for the symmetrical clustering game, the probability that a player declares itself as cluster head, i.e. p, is equal to the symmetric mixed strategy Nash Equilibrium, which is given below:

$$p = 1 - [(w_2C + w_3H + w_4O - w_1E)/V]^{\frac{1}{N-1}} \tag{2}$$

Proof: At first, we should compute the Nash equilibrium of our mixed strategy game. To achieve this goal, the methodology presented in [25] is used. Firstly, the payoff of each strategy is calculated. The expected payoff for *DCH* strategy is $U_{DCH} = V + w_1E - w_2C - w_3H - w_4O$, as the payoff is independent of the other players strategies. The expected payoff for playing *DO* strategy can be computed using the following relation:

$$\begin{aligned} U_{DO} &= p\{\text{no one declares itself as } CH\} \times 0 + \\ &+ p\{\text{at least someone else declares itself as } CH\} V = \\ &= V\left(1 - p\{\text{no one else declares itself as } CH\}\right) = \\ &= V\left(1 - q^{N-1}\right) = V\left(1 - (1-p)^{N-1}\right) \end{aligned} \tag{3}$$

To calculate equilibrium, we should solve the following equation in which the payoff of the two *DCH* and *DO* strategies are equal. In other words, no player wants to change its strategy.

$$V + w_1E - w_2C - w_3H - w_4O = V\left(1 - (1-p)^{N-1}\right) \tag{4}$$

Solving Equation (4) gives us the probability p that corresponds to the mixed strategy Nash equilibrium:

$$p = 1 - [(w_2C + w_3H + w_4O - w_1E)/V]^{\frac{1}{N-1}} \tag{5}$$

Let $\lambda = w_2C + w_3H + w_4O - w_1E$, so the probability p can be written as:

$$p = 1 - \left(\frac{\lambda}{V}\right)^{\frac{1}{N-1}} \tag{6}$$

Clearly, $\lambda/V<1$, so, the value of p in Equation (6) always lies in the [0, 1] interval. As the number of players increases, the probability p decreases. In other words, the number of cluster heads becomes less as the number of players increases and the sensor nodes become less cooperative. The probability that at least one player plays *DCH* can be computed as below:

$$\begin{aligned} p_1 &= p\{\text{at least one sensor node declares itself as } CH\} = \\ &= 1 - p\{\text{no one declares itself as } CH\} = 1 - (1-p)^N \end{aligned} \tag{7}$$

According to the Equation (6), we have:

$$p_1 = 1 - \left(\frac{\lambda}{V}\right)^{\frac{N}{N-1}} \tag{8}$$

From the Equations (6) and (8) we can observe that if there is just one player participating in clustering game, the probabilities p and p_1 are equal to 1. This means that if there is only one sensor node left in the network, it always declares itself as cluster head. For two players, $p = 1 - (\lambda / V)$, and $p_1 = 1 - (\lambda / V)^2$. As N tends to infinity the following relation:

$$\lim_{N\to\infty} p = 0 \tag{9}$$

$$\lim_{N\to\infty} p_1 = 1 - (\lambda / V) \tag{10}$$

Thus, the higher the number of sensor nodes, the less the probability of at least one sensor node declares itself as cluster head. Figures 1 and 2 show the values of these probabilities as N increase for five different values of (λ / V) as (0.1, 0.3, 0.5, 0.7, and 0.9).

C. Parameters Description

There are four parameters, which are considered to design a clustering game as E, C, H, and O. This section describes reasons behind the selection of these parameters.

C.1. Residual Energy of the Sensor Node (E)

Energy consumption is one of the important parameters in WSNs. The goal of clustering sensor nodes is reducing energy consumption in wireless sensor networks. When we want to choose a sensor node as cluster head, we should try to select a sensor node with maximum possible energy. From the Equation (6), it can be considered, the higher the residual energy of sensor node, the higher the probability of being a cluster head.

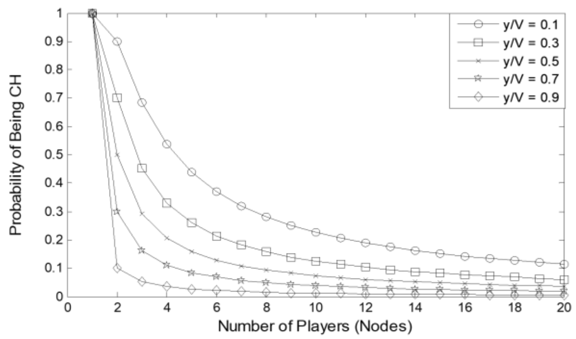

Figure 1. Probability p of being CH versus the total number of players, (sensor nodes)

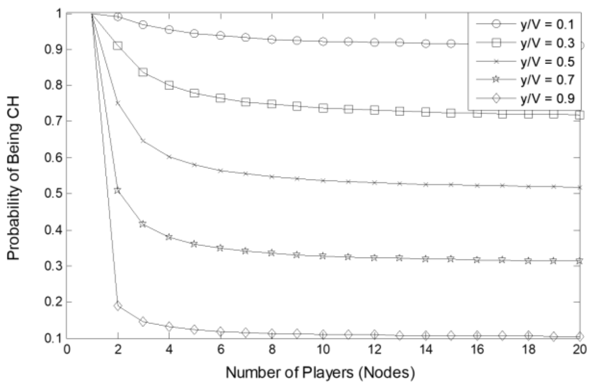

Figure 2. Probability p_1 of at least one player being CH versus the total number of players (sensor nodes)

C.2. Cost of Being a Cluster Head (*C*)

When a sensor node becomes cluster head, it should aggregate the received data from the other sensor nodes in cluster and transmit them to the base station. Being a cluster head has some costs, which depend on the number of sensor nodes in the cluster and the distance of the cluster head to the base station. Thus, a sensor node with minimum cost should be selected as cluster head. From the Equation (6), it can be considered, the higher the cost of being a cluster head, the less the probability of being a cluster head.

C.3. Distance of Sensor Node to the Base Station (*H*)

When a sensor node becomes a cluster head, other sensor nodes in that cluster forwards their data to the cluster head. Cluster heads aggregate data and send them to the base station. If the cluster head is far from the base station, it requires more energy to transmit data. Therefore, it is important to try to select a sensor node as cluster head with minimum possible distance to the base station.

It is desirable that the sensor nodes closer to the base station become cluster head while the other ones remains as ordinary sensor nodes. In other words, smaller number of sensor nodes wants to become cluster head. In this model, cluster heads transmit data to the base station directly without getting help from other sensor nodes. From the Equation (6), it can considered, the larger the distance of sensor node to the base station, the less the probability of being cluster head.

C.4. Distance of other Neighbors to the Sensor Node (*O*)

After sensing data, each sensor node forwards its data to the cluster head. Therefore, it is better for the sensor node to be closer to the cluster head. In other words, if the cluster head is almost near to the center of its neighboring sensors, then the distance between them is less. At the best, all sensor nodes want to become cluster head. In this way, they can ignore forwarding their data to the cluster head and can send them to the base station directly.

With these descriptions of the last two parameters, it can be concluded that these two parameters are in contrast with each other. From one hand, the distance to the base station prevents sensor nodes to become cluster head. On the other hand, the distance of other neighbors to the sensor node encourages all the sensor nodes to become cluster head. Hence, it is necessary to find a good tradeoff between these two parameters. From the Equation (6), it can considered, the larger the distance of sensor node to its neighbors, the less the probability of being a cluster head.

D. Costs and Energy Dissipation

As discussed in the previous section, a clustering game was designed containing four parameters and used to find a probability p, which determines the probability to become cluster head for each sensor node. After selection of cluster heads, the clusters will be created and then, the member of each cluster will be determined. Each sensor node joins to the cluster with the nearest cluster head. It is assumed that the base station have unlimited energy power. Therefore, at the beginning, the base station broadcasts a message with a certain power in the whole network. Any sensor node who receives this message, computes its distance to the base station based on the received signal.

This computation enables it to choose the most appropriate cluster. Every sensor node senses the environment, collects data depending on its application, and then sends the collected data to its cluster head directly. Cluster heads aggregate these data and forward them to the base station in one-hop. We assume that the following properties are hold for the sensor network:

- The locations of the sensor nodes are fixed.
- The sensor nodes have similar capabilities of processing and communication, but there is not any constraint on the value of their initial power.
- The sensor nodes are distributed uniformly in network.
- There is only one base station with unlimited energy, which is far enough from the sensor nodes.
- Links are symmetric, so transmitting a packet or message from node 'A' to node 'B' requires the same amount of energy as transmitting a packet or message from node 'B' to node 'A'.
- The sensor nodes are location un-aware.
- Battery recharge is not available for sensor nodes. Therefore, efficient energy aware protocols are required for reducing energy consumption.

Our proposed approach consists of several rounds. Like LEACH, each round has two phases, a setup phase and a steady state phase. In the first phase, cluster heads are selected using DCGT algorithm and the clusters are formed. Then, in the second phase, data is transmitted to the base station.

D.1. Setup Phase

Depending on parameters, each sensor node computes its probability to become a cluster head. Each sensor node creates a random number between zero and one. If the number is less than the computed probability, the sensor node becomes a cluster head. Then each cluster head broadcasts a message and introduces itself as cluster head to the network. Each ordinary sensor node that receives this message, computes the distance between itself and the related cluster head. At the end, the sensor node joins to the cluster that is closer to its cluster head.

Then, each sensor node sends a message to its cluster head and declares itself as a member of that cluster. Accordingly, all clusters are created and all the cluster heads know their members. In addition, all ordinary sensor nodes know their cluster heads and every ordinary sensor node is the member of only one cluster. Each cluster head uses TDMA protocol for receiving data form its members and the other sensor nodes, which is not their time slot to send their data, are deactivated to save their energy.

D.2. Steady State Phase

After sensing, each ordinary sensor node sends its data to its cluster head. The spent energy when a sensor node i transmit a packet of k bit to its cluster head is calculated using the following equation:

$$E_{i,CH_i} = k\,(E_{elec} + E_{amp2} \times d_{i,CH_i}^2) \quad (11)$$

where, E_{elec} is the spent energy at the transmitter's electronic circuitry and E_{amp} is the spent energy by the transmitter's amplifier to achieve the required signal level at the receiver. There are usually two variations for this parameter, E_{amp2} is used for short distances (from the sensor node to its cluster head) while E_{amp4} is used for long distances (from the cluster head to the base station), $d_{i,CHi}$ denotes the distance between a sensor node i and its cluster head (CH_i). On the other hand, the energy spent by the receiver for receiving a data packet can be calculated using the following equation:

$$E_{rx} = kE_{elec} \quad (12)$$

One of the main advantages for clustering sensor nodes is as follows. After receiving all data from ordinary sensor nodes, cluster heads aggregate data. That is, cluster heads decrease the amount of data to be transmitted by aggregating them and then send the aggregated data to the base station. The amount of energy, which is spent for aggregating data given by the following equation:

$$E_{aggr} = N_u kE_{fuse} \quad (13)$$

where, N_u denotes the number of members in the cluster and E_{fuse} is the energy spent to aggregate one bit. In addition, the energy spent by the cluster head to transmit the aggregated data to the base station is:

$$E_{CH_i,BS} = k\,(E_{elec} + E_{amp4} \times d_{CH_i,BS}^4) \quad (14)$$

where, $d_{CHi,BS}$ denotes the distance from the cluster head i to the base station.

Another parameter, which is used in designing the clustering game, is C. Each sensor node calculates this parameter using the following equation:

$$C_i = N_u E_{rx} + E_{aggr} + E_{CH_i,BS} \quad (15)$$

Using Equation (7), each sensor node computes the probability of being a cluster head. At each round, some of the sensor nodes become cluster head according to the computed probability and receive data from their members in the cluster. Then, they aggregate the data received from different members and send them to the base station. In this way, the energy consumption of sensor nodes are reduced due to transitions they do. As described before, cluster heads spend much more energy than ordinary sensor nodes, so a proper selection of cluster head is vital in order to distribute the energy consumption of sensor nodes appropriately.

To distribute energy consumption of sensor nodes across the network, at each round, if a sensor node is selected to be a cluster head, its probability is set to zero until all of its neighbors (which are in its radio range) become cluster head at least for one time. Here, it is assumed that all of the sensor nodes are neighbor to each other and so, all sensor nodes are in the radio range of each other. Therefore, the number of sensor nodes which participate in the cluster head selection game is N in the first round.

Assuming that $N_{CH}(1)$ node become cluster head in the first round, then the number of sensor nodes which participate in the cluster head selection game in the second round will be equal to N - $N_{CH}(1)$. If the cluster head selection repeats, at round $j + 1$, the number of sensor nodes participating in the cluster head selection game can be calculated using the following equation:

$$N_{play}(j+1) = N - \sum_{k=1}^{j} N_{CH}(k) \quad (16)$$

After all the neighbors of a sensor node are selected to become cluster head, that node again computes its probability using the Equation (7).

IV. PERFORMANCE EVALUATION AND SIMULATION RESULTS

For evaluating efficiency of the DCGT, several simulation experiments are done using MATLAB and then the results are compared to a well-known clustering algorithm 'LEACH' along with another clustering algorithm which is one of the state of the art intelligent clustering algorithms, CORSS.

A. Simulation Setups

In our simulations, the network dimension is assumed 150m×150m with 100 (N) sensor nodes, which are distributed uniformly in the network. In addition, the base station is located at (150,150). The parameter values in Table 2 are used for the energy consumption models mentioned in Equations (11) to (15) [6].

The initial energy of all sensor nodes is set to E_{init} = 0.5 J. In addition, we have assumed that each packet has a fixed length of k = 2000 bit. Furthermore, the radio range of each cluster head is assumed large enough so that it is possible for each cluster head to transmit its data directly (in one hop) to the base station. In order to find proper values for weights w_1 to w_4 in Equation (8), a genetic algorithm was used which resulted in these values, w_1 = 0.837, w_2 = 0.793, w_3 = 0.544 and w_4 = 0.359. In addition, we considered V = 100, which is sufficiently larger than other parameters in the network. Averaging ten independent simulations to validate the obtained results compute all metrics.

Table 2. The Values for the energy expenditure parameters [6]

E_{elec}	50 nJ/bit
E_{amp2}	10 pJ/bit/m^2
E_{amp4}	0.0013 pJ/bit/m^4
E_{fuse}	5 nJ/bit

B. Evaluation of Network Lifetime

The most important performance factor of clustering methods is the network lifetime. Network lifetime is the number of rounds that a certain percent of initial sensor nodes are still alive. Figure 3 illustrates the number of alive sensor nodes in terms of round number.

Based on numerical results in rounds 1400, 1600 and 1800, the number of alive nodes in the network in the DCGT algorithm is 91, 77, and 61, respectively, while the number of alive nodes in the CROSS and the LEACH is 85, 69 and 48 and 86, 69 and 38.

Also, in the LEACH and the CROSS methods, all nodes die in rounds 1963 and 2244, respectively, while the DCGT has at least one or two alive nodes until the round 2300th. Moreover, first node death in the LEACH and the CROSS is earlier than the DCGT. Considering the first node death as network lifetime, the DCGT increases network lifetime around 27.1% and 28% compared with two other methods.

C. Evaluation of Energy Consumption

As the energy consumption evaluation, Figure 4 demonstrates the average residual energy of all sensor nodes in different rounds (500, 1000, 1500, and 2000). According to this figure, average residual energy of sensor nodes in the DCGT is greater than the LEACH and the CROSS in all rounds.

So it can be concluded that the DCGT has better distribution for energy dissipation than the LEACH and the CROSS methods. Figure 4 shows that, in round 1500, the DCGT has 1.23 times higher energy than the LEACH and 1.27 times higher energy than the CROSS. In addition, in round 1000, the DCGT has 1.06 and 1.08 time's higher energy than those two methods, respectively.

D. Evaluation of Network Lifetime with Heterogeneous Initial Energy for Sensor Nodes

As mentioned before, residual energy of sensor nodes is an important parameter in the DCGT. In order to analyze the effect of parameter on the network lifetime, another simulation considered. Therefore, heterogeneity in initial energies of sensor nodes has been done.

In this simulation, the initial energy of 70% of the sensor nodes is set to 0.5 J but it is set to 0.25 J for other sensor nodes. Figure 5 shows that, the DCGT increases the network lifetime considerably and generates better results in comparison with the CROSS and the LEACH.

Also, the first node and the last nodes die later in the DCGT. For example, the first sensor node death in the DCGT, CROSS and LEACH is respectively in rounds 1113, 555 and 493 which means that it dies 2 and 2.25 times later in DCGT compared with the LEACH and the CROSS, respectively.

The reason is that, in the DCGT algorithm the residual energy of sensor nodes is one of the effective parameters in computation of the probability of being a cluster head for each sensor node. However, the CROSS and the LEACH do not consider this parameter in their cluster head selection functions. Therefore, they cannot provide efficient scenarios in which sensor nodes have heterogeneous initial energies.

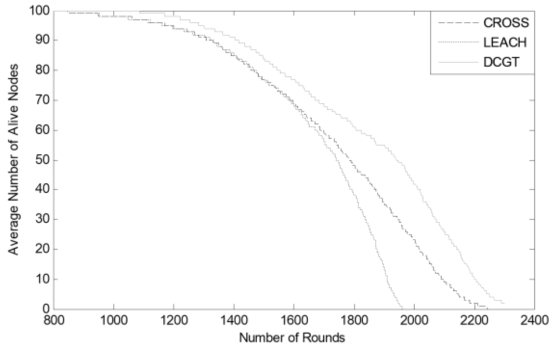

Figure 3. Average number of alive nodes in each round

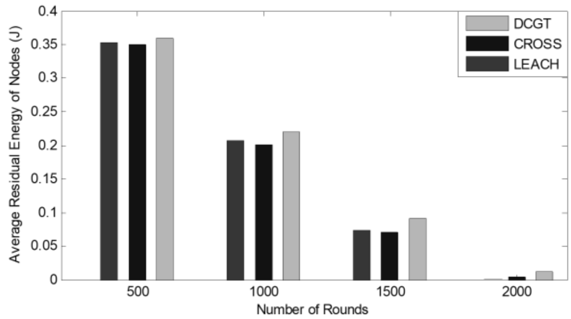

Figure 4. Number of rounds versus the average residual energy of nodes

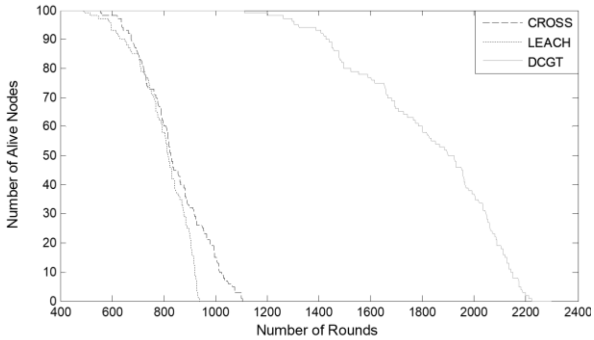

Figure 5. Number of alive sensor nodes versus average numbers of rounds when the initial energy powers of sensor nodes are heterogeneous

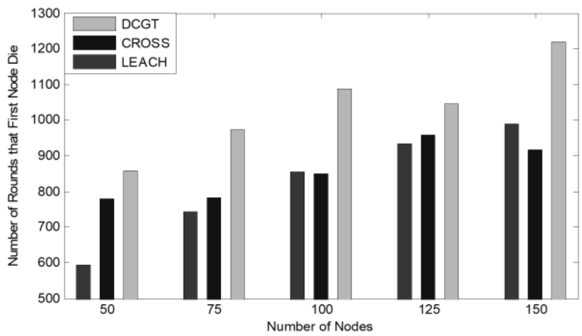

Figure 6. Number of sensor nodes versus the numbers of rounds those 50% nodes alive

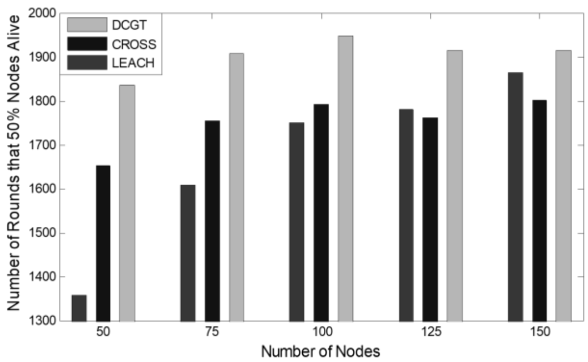

Figure 7. Number of sensor nodes versus the number of rounds that first node death

E. Evaluation of Network Lifetime When 50% Nodes Alive and First Node Die

For more analysis of the efficiency of the DCGT, in this section, simulations with different number of sensor nodes in the network are accomplished. Figure 6 shows the number of rounds in which 50% of the sensor nodes are alive (scenarios with different number of sensor nodes). Again, the DCGT provides more desirable results compared with the CROSS and the LEACH. As a result, the network lifetime in the DCGT is longer than two other methods when the numbers of sensor nodes vary.

Hence, the DCGT has no limitation of number of sensor nodes in the network and it can be used in networks with the different number of sensor nodes. For example, when the number of nodes is 75, 100, and 125, the DCGT increases the network lifetime by 15.7%, 10.25%, and 7.29% compared with the LEACH and by 7.85%, 8.2%, and 8.33% compared with the CROSS. The last evaluation phase of the DCGT algorithm is shown in Figure 7. In this evaluation, different number of sensor nodes are used and the number of rounds that first sensor node dies is considered as a network lifetime.

Numerical results in Figure 7 argue that the DCGT prolongs the network lifetime in comparison with the CROSS and the LEACH. For example, when the number of sensor nodes is 75, 100 and 125 in the network, first node death in the DCGT is 30.95%, 27.3%, and 12.54% later than the LEACH and 24.42%, 28.2% and 9.48% later than the CROSS.

V. CONCLUSIONS AND FUTURE WORK

In this paper, a game theoretical approach is proposed which can be used in clustering of wireless sensor networks to reduce the overall energy consumption. To design the game, four parameters (residual energy, the cost of being a cluster head, distance to the base station, and distance to its neighbors for each sensor node) have been considered. Based on the game table, it is shown that the Nash equilibrium of pure strategies is equivalent to the case where only one sensor node declares itself as the cluster head but the others do not.

Since, there is no symmetrical equilibrium in pure strategies, a mixed strategy equilibrium is computed which represents the probability of each sensor node to be the cluster head. In addition, using several simulation it was shown that the computed equilibrium probability could be used in real sensor networks to distribute energy consumption among the sensor nodes and to increase the network lifetime by choosing the cluster heads appropriately. In comparison to the LEACH and the CROSS algorithms, It was shown that the proposed clustering algorithm is able to reduce energy consumption and increase the lifetime of the network more efficiently.

Furthermore, unlike those two algorithms, there is no limitation on the equation of initial energy of sensor nodes in the DCGT. Thus, the proposed algorithm can be used in the networks with heterogeneous energy of sensor nodes. As the future work, we will extend our game for unequal clustering of sensor nodes. That is, clusters near the base station have smaller transmission range compared with the clusters that are located far from the base station. In addition, we will attempt to change the game so that it is no longer required to assume that all nodes are neighbors of each other.

REFERENCES

[1] I.F. Akyildiz, M.C. Vuran, "Wireless Sensor Networks", Wiley, 2010.
[2] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, "Wireless Sensor Networks - A Survey", Journal of Computer Networks, Elsevier, Vol. 40, Issue 8, pp. 393-422, 2010.
[3] J. Yick, B. Mukherjee, D. Ghosal, "Wireless Sensor Network Survey", Journal of Computer Networks, Elsevier, Vol. 52, pp. 2292-2330, 2008.
[4] S. Naeimi, H. Ghafghazi, C.O. Chow, H. Ishii, "A Survey on the Taxonomy of Cluster Based Routing Protocols for Homogeneous Wireless Sensor Networks", Journal of Sensors, Vol. 12, Issue 6, pp. 7350-7409, 2012.
[5] R. Machado, S. Tekinay, "A Survey of Game-Theoretic Approaches in Wireless Sensor Networks", Journal of Computer Network, Elsevier, Vol. 52, pp. 3047-3061, 2008.
[6] N. Sadagopan, M. Singh, B. Krishnamachari, "Decentralized Utility Based Sensor Network Design", Journal of ACM Mobile Networks and Applications, Vol. 11, Issue 3, pp. 341-350, 2006.
[7] A. Agah, K. Basu, S.K. Das, "Preventing DoS Attack in Sensor Networks - A Game Theoretic Approach", IEEE International Conference on Communications, No. 5, pp. 3218-3222, 16-20 May 2005.
[8] M. Kodialam, T.V. Lakshman, "Detecting Network Intrusions via Sampling - A Game Theoretic Approach", 22th Conference of the Computer and Communications, IEEE, No. 3, pp. 1880-1889, 30 March-3 April 2003.
[9] S. Bayrakli, S.Z. Erdogan, "Genetic Algorithm Based Energy Efficient Clusters (GABEEC) in Wireless Sensor Networks", 3rd International Conference on Ambient Systems, Networks and Technologies (ANT), No. 10, pp. 247-254, 2012.
[10] S. Babaie, S. Shokraneh, A. Ghaffari, A. Jahangiry, "CCGA - Clustering Based on Cluster Head with Genetic Algorithm in Wireless Sensor Network", IEEE International Conference on Computational Intelligence and Communication Networks (CICN), Bhopal, pp. 367-371, 26-28 November 2010.

[11] M. Emamjomeh, B. Arisian, "A Price-Based Optimal Routing Algorithm in Wireless Sensor Networks", 7th IEEE International Conference on Communications Networking and Mobile Computing, Wuhan, pp. 1-6, 23-25 September 2011.
[12] E. Saeedian, M. Jalali, M.M. Tajari, M.N. Torshiz, G. Tadayon, "CFGA - Clustering Wireless Sensor Network Using Fuzzy Logic and Genetic Algorithm", IEEE, 7th International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM), Wuhan, pp. 1-4, 23-25 September 2011.
[13] S.J. Dastgheib, H. Oulia, H. Gholamishiri, A. Ebrahimi, "A Proposed Fuzzy Method to Detect Faulty Nodes in Wireless Sensor Network Clustering Structure", International Journal on Technical and Physical Problems of Engineering (IJTPE), Vol. 4, Iss. 8, No. 2, pp. 71-75, 2012.
[14] W.R. Heinzelman, A. Chandrakasan, H. Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Micro sensor Networks", IEEE, 33rd Hawaii International Conference on System Sciences, 4-7 January 2002.
[15] R.S. Chang, C.J. Kuo, "An Energy Efficient Routing Mechanism for Wireless Sensor Networks", IEEE, 20th International Conference on Advanced Information Networking and Applications, No. 2, pp. 1-5, 2006.
[16] M.J. Handy , M. Haase , D. Timmermann, "Low Energy Adaptive Clustering Hierarchy with Deterministic Cluster-Head Selection", IEEE, 12th International Workshop on Mobile and Wireless Communication Networks, pp. 368-372, 2002.
[17] O. Younis, S. Fahmy, "HEED - A Hybrid, Energy-Efficient, Distributed Clustering Approach for Ad-hoc Sensor Networks", IEEE, Journal of Mobile Computing, Vol. 3, Issue 4, pp. 366-379, 2004.
[18] B. Gong, L. Li, S. Wang, X. Zhou, "Multi-Hop Routing Protocol with Unequal Clustering for Wireless Sensor Networks", IEEE Journal of Computing, Communication, Control, and Management, Vol. 2, pp. 552-556, 2008.
[19] S. Hussain, A. Azim, J.H. Park, "Energy-Efficient Virtual MIMO Communication for Wireless Sensor Networks", Journal of Telecommunication Systems, Springer, Vol. 42, pp. 139-149, 2009.
[20] V. Tran, T. Miyoshi, "Adaptive Routing Protocol with Energy Efficiency and Event Clustering for Wireless Sensor Networks", IEICE, Transactions on Communications, Code E91.B, pp. 2795-2805, 2008.
[21] H. Barati, A. Movaghar, A.M. Rahmani, A. Sarmast, "A Distributed Energy Aware Clustering Approach for Large Scale Wireless Sensor Network", Int. Journal on Technical and Physical Problems of Engineering (IJTPE), Vol. 4, Issue 13, No. 4, pp. 125-132, 2012.
[22] H. Jing, H. Aida, "A Cooperative Game Theoretic Approach to Clustering Algorithms for Wireless Sensor Networks", IEEE, Pacific Rim Conference on Communications, Computers and Signal Processing, Victoria, pp. 140-145, 23-26 August 2009.
[23] J.T. Wang, Z.G. Chen, X.H. Deng, "A Trustworthy Energy-Efficient Routing Algorithm Based on Game Theory for WSN", Int. Communication Conference on Wireless Mobile and Computing (CCWMC), IET, Shanghai, pp. 192-196, 7-9 December 2009.
[24] G. Koltsidas, F.N. Pavildou, "A Game Theoretical Approach to Clustering of Ad-Hoc and Sensor Networks", Journal of Telecommunication Systems, Springer, Vol. 47, pp. 81-93, 2011.
[25] M.J. Osborne, "An Introduction to Game Theory", University of Toronto, 2000.

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