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A GAME THEORETIC APPROACH FOR ENERGY OPTIMIZATION IN CLUSTERED WIRELESS AD HOC SENSOR NETWORKS

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ABSTRACT

In this paper, our objective is to use the game-theoretic approach for clustered wireless ad-hoc networks to optimize system lifetime. Game theory (GT) has been exploited in the domain of biology and economics, but lately it is applied in routing and packet forwarding in Wireless Ad hoc Networks (WANETs). However, the clustering topic, concerned with self-directedness of sensor nodes into big groups, has not been examined under this model. Distance-based Clustered Routing For Selfish Sensors (D-CROSS) protocol assists in accomplishing energy conservation where every single sensor node is nominated as cluster head (CH) with zero probability rule (ZPR). Our analysis follows the non-cooperative game theoretic approach where each sensor node selfishly plays and tries to preserve its own energy and maximize its lifetime. We demonstrate here the Nash Equilibrium for mixed and pure strategies and anticipated payoffs. The comparison of the D-CROSS protocol with the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol through simulations demonstrates that D-CROSS achieves improved performance in terms of network lifetime.

1. INTRODUCTION

Wireless Ad hoc Network (WANET) is basically a distributed network and it does not depend upon pre-existing infrastructure. Each such network consists of nodes with an external or internal antenna, radio transceiver, and battery. Each node is responsible for routing by packet forwarding.

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Sensor nodes may extend from few to thousands. Due to decentralized nature, WANET is used in emergency conditions such as natural disasters, temperature sensing, sound sensing, and military conflicts. Sensor nodes are normally trivial, autonomous, cheaper, and battery efficient, but they have limited energy capacity. So there is a decent energy-efficient mechanism required for long-lasting battery efficiency (Tong, Jiyi, He, Jinghua, & Munyabugingo, 2013; Das & Pal, 2019). Sensor nodes may extend from few to large numbers, so there is a need for predefined mechanism to enhance the performance of network. The clustering technique (Ye, Li, Chen, & Wu, 2005; Kumari, Singh, & Aggarwal, 2019) is a good way to enhance the battery power and for improving the network's lifetime. Network lifetime (NL) is an essential element in WANETs. Network lifetime is demonstrated as the lifetime of the individual node among all others who discharges its 99.9% energy. Once the sensing task is completed then the further data is transformed to the main center, which executes next tasks.

Game theory (Koltsidas & Pavlidou, 2008) is an emerging field and it is used as a tool in ad hoc networks. It has so many applications in economy, biology and mathematics, and networking fields. Game theory is characterized by number of players, some strategies, and the Nash Equilibrium (NE) which is a substantial factor in GT. In (Tan et al., 2018), Repeated Game in Small World Networks (RGSWN) framework was proposed by scheming a robust and efficient ad hoc network. Initially, WANET with trivial-worldwide characteristics was assembled by forming ‘‘communication shortcuts’’ within multiple-radio sensor nodes. The path length decreases through averaged accelerating times in-network; in the meantime high clustering coefficients enhance network robustness. Many algorithms for network lifetime improvement have been discussed so far. In direct communication, data or information from transmitter to receiver reaches using single link. Sensor nodes deliver this information to the receiver or sink directly without any relay or intermediate node (Félegyházi, Buttyán, & Hubaux, 2003; Felegyhazi, Hubaux, & Buttyan, 2006; Nurmi, 2004). In some cases, sink is located far away from transmitter so this causes early battery drainage for nodes that have to deliver information directly to the sink, so this causes poor network lifetime. This issue can be solved if data is transmitted with high power or sink is located near to transmitter. In (Baker et al., 2018), game theory was used in WSNs to expand the energy proficiency of a network lifetime. Game theory is always appropriate for such complications as it is used for network-level or node to boost the decision-making competences of WSNs. Many power-efficient algorithms use relay nodes to transfer data from transmitter to destination (Stojmenovic & Lin, 2001; Rodoplu & Meng, 1999). The route selection method of these protocols is different from each other. By using intermediate nodes in MinimumTransmission Energy (MTE) causes battery drainage efficiency. In (Rai & Rai, 2019), a two-stage cooperative (TSC) communication model was considered and the main helper was inserted to handle the cooperation from helping set. Afterward, the two-stage link cost function was articulated under such circumstances where the magnitude of residual energy was presented to use for numerous strategy goals. However, the literature conveys different studies about conventional energy-efficient systems but several of these researches have deficiency of clustering based efficient ad hoc networks for an efficient network lifetime.

In this paper, Distance-based Clustered Routing For Selfish Sensors (D-CROSS) protocol was proposed to improve the ad hoc network lifespan. The cluster head (CH) was selected based on clustering game and Zero Probability Rule (ZPR) was considered for selection of each sensor node as CH. We compared the relation of D-CROSS and LEACH protocol for lifetime under such situation, where the number of nodes is not constant. We have found that D-CROSS have better performance than LEACH protocol for WLANs. The rest of the paper is structured as follows. Section II defines the radio model and energy dissipation. The game-theoretical approach and selection of CH methodology are demonstrated in section III. Section IV deals with the results and simulations for D-CROSS model and section V illustrates the conclusion.

2. RADIO MODEL AND ENERGY DISSIPATION

Radio model consists of energy dissipation on the receiver and transmitter side (Heinzelman, Chandrakasan, & Balakrishnan, 2000). For radio model, $e_{elec} = 50nJ/bit$ is taken into account for transmitter and for receiver side. Moreover, $e_{amp2} = 10pJ/bit/m^2$ is considered for this model. While $e_{amp4} = 0.0013pJ/bit/message$ are taken into account. These assumptions are taken into account for adjusting signal to noise ratio $E_b=N_o$ to its acceptable level. $E_{T\ x\text{-}amp2}(I, S) = I_{\ amp2} *S^{\beta}$, where I represents packets length, S represents distance between transmitter to the receiver and β =2 for free space model. Following （1） shows energy dissipation of transmitter amplifier an（2）shows total energy dissipation on transmitter side.

$$E_{Tx-amp}(I,S) = I * e_{amp2} * S^2 \tag{1}$$

$$E_{i,CH_i} = I * e_{elec} + I * e_{amp2} * S^2 \tag{2}$$

whereas (3) represents energy dissipation on the receiver side. The simple radio model is illustrated in Figure1.

$$E_{rx}(S) = I * e_{elec} \tag{3}$$

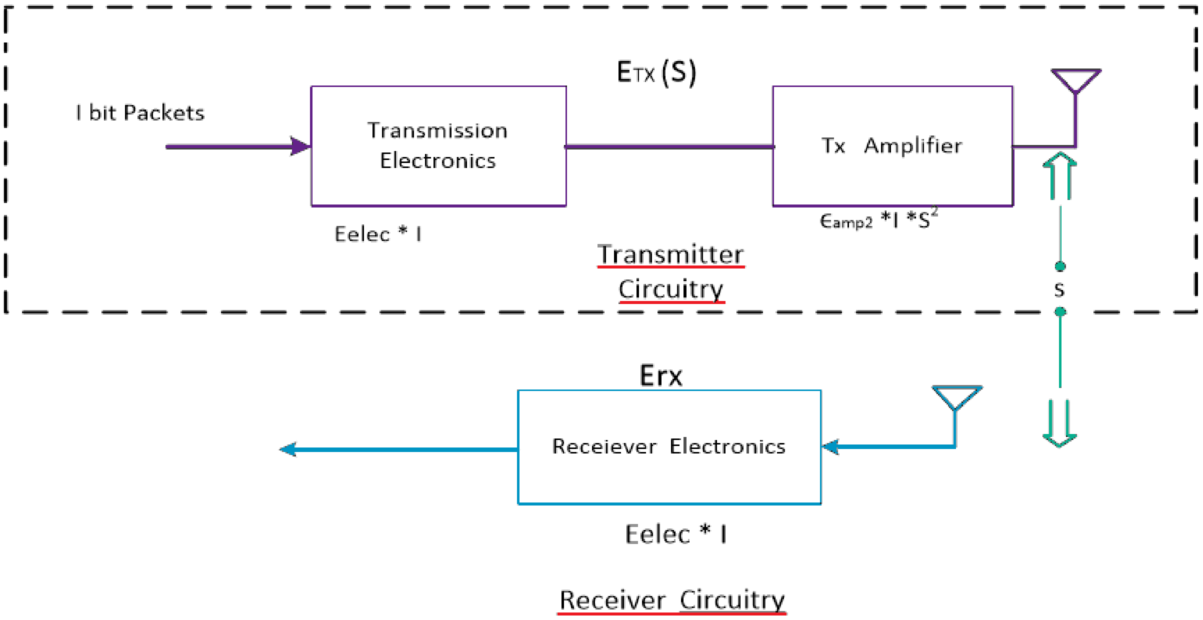

Figure 1: The Radio Model.

The route selection method of these protocols is different from each other. By using intermediate nodes in Minimum Transmission Energy (MTE) causes battery drainage efficiency. If we have three nodes as presented in Figure 2 (a), then transmission from sensor node *A* to sensor node *C* by using intermediate sensor node *B* can be done by fulfilling given conditions as given in (4) and (5)

$$E_{Txx-amp}(I, S = S_{AB}) + E_{Txx-amp}(I, S = S_{BC}) < E_{Txx-amp}(I, S = S_{AC}) \tag{4}$$

$$S_{AB}^2 + S_{BC}^2 < S_{AC}^2 \tag{5}$$

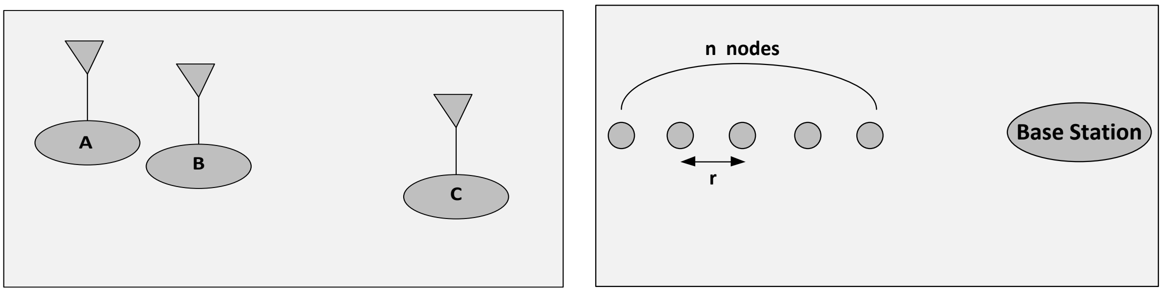

Figure 2: The transmission from A to C by using B (a), the Linear model (b)

In the MTE routing protocol, data packets traverse through *n* nodes. As a result, there are *n* transmissions and *n-1* receptions. Figure2 (b) illustrates Linear Network where *r* is distance between two consecutive nodes. In direct transmission, energy expenditure of a single *I* bit message from one node to base station is elaborated from (6), where *nr* is defined as the distance between receiver (Rx) and transmitter (Tx).

$$E_{direct} = E_{Tx}(I, S = n * r) \tag{6}$$

$$E_{direct} = I * e_{elec} + I * e_{amp2} * (nr)^2 \tag{7}$$

$$E_{direct} = I\,(e_{elec} + e_{amp2} * (nr)^2\,) \tag{8}$$

Energy expenditure in MTE routing protocol for n transmitters and $n-1$ receptions is given as

$$E_{MTE} = n * E_{Tx}(I, S = r) + (n-1) * E_{rx}(I) \tag{9}$$

$$E_{MTE} = n * \left(e_{elec} * I + e_{amp2} * I * r^2\right) + (n-1) * E_{rx} * I \tag{10}$$

$$E_{MTE} = I\left((2n-1) * e_{elec} + e_{amp2} * n * r^2\right) \tag{11}$$

Energy expenditure of MTE routing protocol should be less than that of direct communication protocol i.e.,

$$E_{direct} < E_{MTE} \qquad (12),$$

$$I * e_{elec} + I * e_{amp2} * (nr)^2 < I\left((2n-1) * e_{elec} + e_{amp2} * n * r^2\right) \quad (13),$$

$$\frac{e_{elec}}{e_{amp2}} > \frac{nr^2}{2} \quad (14).$$

Energy-efficient protocols depend upon distribution of nodes (Poe & Schmitt, 2009)and network topology. The clustering protocol is practiced for energy efficiency in WANETs. Nodes are organized in a specific pattern and they form a cluster. All nodes elect *CH* among themselves and *CH* is creditworthy for accumulating the information of all other nodes. Ordinary nodes deliver their information to *CH* of group, and afterward the *CH* sends the received data to the base station. Clustering is recognized as an energy proficient technique when compared to the direct communication in WANETs.

3. METHODOLOGY

Wireless sensor networks contain small and sensing nodes that are energy efficient. Communication among these nodes and sink is held due to wireless signals. These networks are gaining popularity due to their use in different atmospheres such as sensing (Michiardi & Molva, 2002) or military applications. The main objective of this sensor network is to improve the lifetime of network. The game theory approach is utilized for decision making capability in wireless ad hoc networks to optimize node level as well as network-level performance.

3.1 GAME THEORETICAL APPROACH

Game theory (Agah, Das, & Basu, 2004) is a theory of decision making under certain conditions and it tries mathematically to understand the performance in strategic circumstances, where each player makes it choice based on other player strategies. It is well-defined as the mathematical practice for designing, predicting and understanding the outcomes of game. Game theory is determined by the number of nodes or players (2 or more), expected to be intelligent, smart, and rational, that interrelate with others by selecting numerous actions, on the basis of their assigned preferences. In game theory, Nash Equilibrium (NE) has much importance and it can be explained as a strategy in game theory where each and every node adopts some specific strategy which they are willing to change in near future. NE for a single time game is different from a repeated game. Low cost, high sensing abilities, and network lifetime improvement are desirable features in wireless ad hoc networks. These features create new areas of applications like monitoring, sensing, and tracking. Game theory is further divided into two types:

1-Noncooperative Games

2-Cooperative Game

In Noncooperative games, each player wants to defeat its opponent player by choosing some strategies from strategic space. Each player wants to maximize its own payoff by reducing the cost of transmitting the data packets. Noncooperative games are further divided into two types such as static games and dynamic games. In static games, each player makes its strategy choice simultaneously without any knowledge of other player choices. These games are normally represented diagrammatically using game table. In dynamic games, each player knows the moves played by another player and they have historic knowledge of this game. These games are normally represented by game trees. Here Nash equilibrium can be found by forwarding induction or through backward induction.

In Cooperative games (Cheng, Gao, Zhang, & Yang, 2019), utility depends upon the strategies of all players in the coalition. Cooperative games describe the outcomes of game only when players play together for overall system payoff improvement. The group of cooperative players is called coalition. The overall goal of this game is to establish such algorithm so no player has any benefit from deviating this strategy. In coalition games *(N, v)*, where *N* shows number of players participating in coalition game and *v* is the utility of coalition game. Repeated games may introduce new equilibrium points and this can force players to play cooperatively. Super Additivity Rule fulfills here which explains that payoff of coalition players is always greater than the sum of individual player payoff such as

$$v(S_1U\,S_2)\ \geq v(S_1)\ + v(S_2) \qquad (15),$$

where S_1 and S_2 are basically the coalition structure, $v(S_1)$ and $v(S_2)$ are the separate payoff, and $v(S_1U\,S_2)$ is joint payoff. Game theory has many applications in the field of economics, biology, engineering, computer science and WANETS (Srivastava et al., 2005).

3.2 DISTANCE-BASED CLUSTERED ROUTING FOR SELFISH SENSORS (D-CROSS)

The D-CROSS routing protocol is basically a non-cooperative game approach in game theory. All sensor nodes behave selfishly here and try to improve their lifespan individually. Each node tries to conserve its energy by refusing the data delivery and hopes that other nodes will perform this task. Nodes are demonstrated as players and they join a clustering game to initiate a campaign for *CH* selection with the same probability. Global knowledge of player's location and how many players are taking part in clustering game should be clear to every other node.

D-CROSS shows performance better to the popular clustering algorithm (LEACH). D-CROSS routing protocol comprises two phases which are named as set-up phase and steady-state phase. First phase deals with the realization of cluster, selection of *CH*, broadcasting the signal of *CH* declaration and scheduling the TDMA based frames for every node. The second phase deals with the data transmission among ordinary nodes to *CH* and *CH* to sink. In D-CROSS, the *CH* selection scenario is revealed as the clustering game well-defined by *CG = (N, S, U)*, where the *N* is total number of nodes in the WANET, *S*= $\{S_i\}$ are the useable strategies to every player or node and *U* is the utility function. *S = (D, N D)* is the available strategy space to each player where *D* stands for declaring itself cluster head and *N D* stands for not declaring itself cluster head. If both players decide not to declare themselves as cluster head then payoff of each player will be zero. If player *A* decides itself as member of *CH* and player *B* choose *N D* then player *B* payoff will be *v* and player *A* payoff will be *v-c* where *c* stands for cost and vice versa for opposite strategy. Strategy *S = (D, N D)* and *S = (N D, D)* both are Nash Equilibrium strategies for this game model. Table 1 depicts the all available payoffs and strategies for all players.

Table 1: The payoffs and strategies for 2 players clustering game.

		Player A	
		Declare	*Not Declare*
Player B	*Declare*	$(v-c, v-c)$	$(v-c, v)$
	Not Declare	$(v, v-c)$	$(0,0)$

Cost (c) basically represents the energy expenditure in data delivery from an ordinary node to CH or from CH to base station. Parameter c depends upon three factors data size, total amount of packets acknowledged, and distance among transmitting node to receiving node (Koltsidas & Pavlidou, 2008). The probability of announcing themselves as a CH is p and probability for not declaring themselves as CH is $q = 1\text{-}p$. Probability of declaring itself CH has the following formula

$$\boldsymbol{P = 1 - (c/v)^{\frac{1}{N-1}}} \qquad (16),$$

whereas $\omega = \frac{c}{v} \leq 1$. Equilibrium probability p will never exceed more than 1. Probability p decreases as the number of players fall which means nodes become less cooperative as total number of nodes increase. Let's take another case where only one node declares itself as cluster head then probability p can be explained as

$$P_A = 1 - (c/v)^{\frac{N}{N-1}} \qquad (17).$$

Probability P and P_A both will be the same only when there is only one player left in the game. For $N = 2$, $p = 1 - \omega$, and $P_A = 1 - \omega^2$. Each sensor node or player that has already assisted as CH, the probability remains zero until all neighboring nodes have assisted as CH. Afterward, it approaches again to the usual mode of probability (p) computation. In ZPR, the node which has served as cluster head will never deviate from this probability because no one will be willing to declare itself cluster head more than one time till all nodes selected as cluster head as this causes payoff reduction. So there is no need to enforce the cooperative behavior to each node, and the cooperation comes up naturally from the rules of game.

3.3 ENERGY CONSUMPTION

A sensor node whenever it is willing to send the K bit packet or data to an alternative sensor node then energy consumes in two ways. Firstly, energy consumes in transmitter side of electronic circuitry denoted by e_{elec}. Secondly some part of energy consumes in amplifying the signal power so receiver can collect that data denoted as e_{amp} according to (Younis & Fahmy, 2004). Some parts of energy consume in data delivery from transmitter to cluster head, some part of energy consumes in data transmission from CH to base station and some part of energy consumes in receiving the packets. Energy consumption in data delivery from ordinary node to cluster head can be represented from this formula

$$E_{i,CH_i} = K * \left(e_{elec} + e_{amp2} * d_{i,CH_i}^2\right) \qquad (18).$$

The energy consumption in data transmission from CH to a particular base station can be represented as

$$E_{CH,sink} = K * \left(e_{elec} + e_{amp4} * d_{CH,sink}^4\right) \qquad (19),$$

where e_{amp2} is square law distance attenuation and e_{amp4} is fourth power distance attenuation. Cost function has the following relationship

$$c = N_u * E_{rx} + E_{aggr} + E_{CH,sink} > E_{i,CH_i} = \delta \quad (20),$$

where N_u is the neighboring node and this is the case where cost is constant. Take a new case when the cost function relies on the number of players or the total number of self-elected cluster heads. So cost can be represented as

$$c = \frac{N}{N_{CH}} c_1 \quad (21).$$

The above expression shows that when the total number of nodes or players increases then the cost function increases relatively or with the addition of the number of cluster heads, cost function reduces. The expression for the cost function for the expected number of *CH's* is given as

$$c = c(p) = \frac{N}{N_p} c_1 = \frac{c_1}{p} \quad (22)$$

For the association of the expected payoff of declaring itself as *CH* and not declaring the cluster head, we have the following expression

$$v - c(p) = v.(1 - (1 - p)^{N-1}) \quad (23),$$

$$c(p) = v.\ (1 - p)^{N-1} \quad (24),$$

$$\frac{c_1}{p} = v.\ (1 - p)^{N-1} \quad (25),$$

or

$$\frac{c_1}{v} = p.\ (1 - p)^{N-1} \quad (26).$$

The maximum value of the above expression is 0.25 when *N* = *2*. Hence if $\frac{c_1}{v}$ < 1/4 then the benefit of delivering the packets is so large that no one player will try to play non-cooperatively. So all players declare themselves as *CH*, no matter what other players decide their strategy. In response to the increment of cost function value, the probability decreases as the number of players increase.

4. RESULT AND DISCUSSION

The transmission and communication capability for a long time of all sensor nodes with other sensor nodes depends upon the battery efficiency. Sometimes there exists a large distance between transmitter and receiver nodes which causes battery drainage very quickly. Mostly sensor nodes behave selfishly and they don't want to transmit the data packets for other nodes which cause the packets or information loss, so there is a need for cooperation from all nodes under all circumstances. Nodes that cooperate form groups and they choose a group leader among themselves for a given round which proceeds towards the battery efficiency. The group leader or CH is responsible for message transmission between ordinary node to sink (receiver). The MATLAB software was used for execution of theoretical results. The graphical representation of probability of declaring itself as cluster head is shown in Figure 3. After the increment of number of nodes (*N*), the probability of declaring itself as cluster head reduces. For higher value of ω, the probability of declaring itself as group leader is found as minimum.

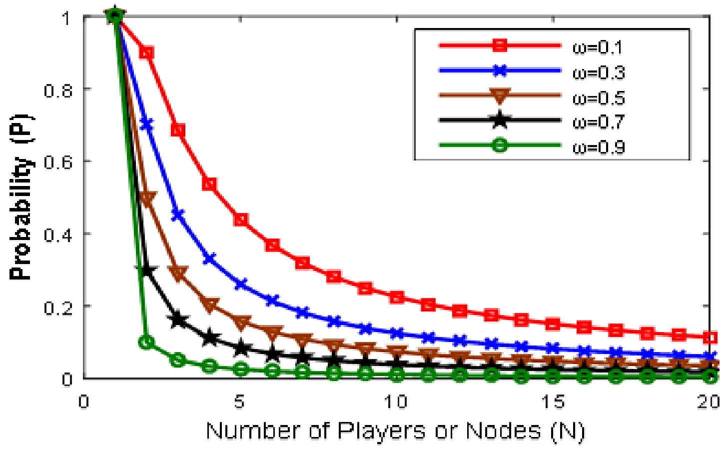

Figure 3: The Probability of declaring itself as Cluster head

Mostly all nodes do not declare themselves as cluster heads so the network can face a condition when only one node plays cooperatively. The probability when at least single node out of all announces itself as *CH* is given as

$$p' = 1 - \left(\frac{c}{Nv}\right)^{\frac{1}{N-1}} \qquad (27).$$

The probability of only one node declaring itself as cluster head is different from the probability of each node declaring itself as *CH*, as given below in Figure 4.

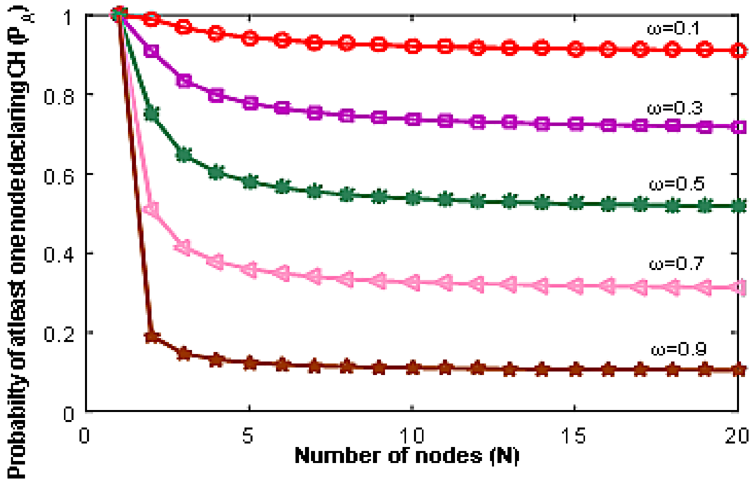

Figure 4: The Probability of at least one node declaring itself as cluster head.

Simulation for a lifetime is conducted in an area of *50 x 50* where $N = 100$ sensor nodes are placed randomly. The sink was positioned at *(25, 125)*. Initially, the total energy for entire nodes was fixed as $E_{init} = 0.5$, however the data packets had a fixed value of $k = 2000$. The path loss (PL) exponent for lower range transmission among two nodes was 2 and for long-range transmission was 4. The average clusters per round were 5% which proposes that after every 20 rounds, all sensor nodes must have served as CH only once. The parameters for consumption of energy are shown in following Table 2.

Table 2: The assumptions for Energy-related parameters.

1	e_{elec}	50nJ/bit
2	e_{amp2}	10 pJ/bit/m2
3	e_{amp4}	0.0013 pJ/bit/m4
4	e_{fuse}	5 nJ/bit/message

The results for numerous cases of ω are shown in Figure 5, and it is clear that the curve for the LEACH protocol is exhibiting a straight line which further explains its independency from the parameter ω. D-CROSS protocol acquires better performance than LEACH in almost all cases except at $\omega = 0.05$. At $\omega = 0.05$ D-CROSS seems to acquire maximum lifetime value. It is generally observed that the selfishness of the sensor nodes leads to a better performance than the LEACH.

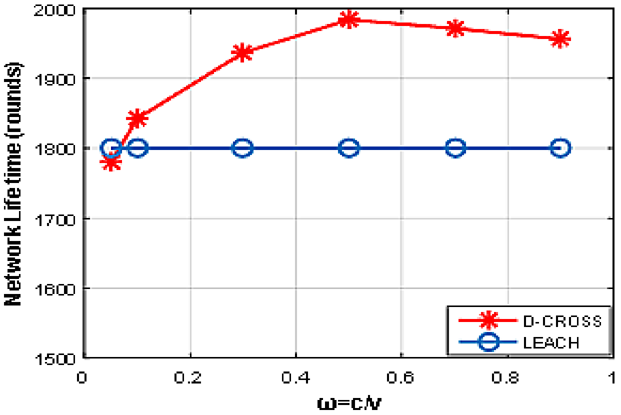

Figure 5: The Network lifetime for D-CROSS under different values of ω and comparison with LEACH.

For explaining the performance of D-CROSS protocols in more detail, the integral value of alive sensor nodes through the passage of rounds is shown below (see the Figure6). We consider only two values of D-CROSS protocol such as $\omega = 0.1$ and $\omega = 0.9$, and afterward, compare these values with LEACH. It is essential to notice that integral value of alive nodes reduces to zero after 2065 for LEACH protocol but at the same instant, the number of alive nodes for both cases in D-CROSS is greater than 50 %, and as a result it proves the feasibility of our proposed D-CROSS protocol.

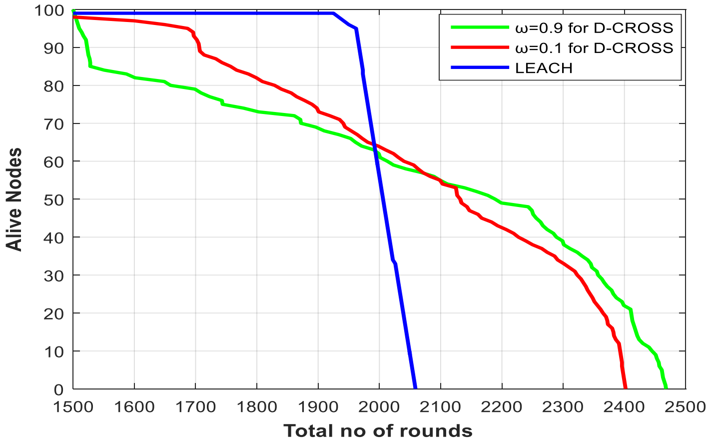

Figure 6: The Number of nodes alive versus a number of rounds for $\omega = 0.1$ and $\omega = 0.9$ for D-CROSS and comparison with LEACH.

Now we are interested in discussing the relation of D-CROSS and LEACH protocol for a lifetime when the numbers of nodes are not constant. We distributed the CROSS algorithm into two types such as D-CROSS1 and D-CROSS2, where D-CROSS1 deals with the equilibrium probability for cluster head declaration and D-CROSS2 deals with probability which maximize the payoff.

The energy values are considered the same as explained before, but in this case we increase the node deployment area from *50 x 50* to *100 x 100*. The percentage of nodes declaring themselves as cluster head for LEACH is taken as 5 %, and for D-CROSS1 and D-CROSS2 the parameter ω is fixed as 0.5. We varied the nodes from 60 to 150 to measure the required results. It is clear that D-CROSS2 performs better results than D-CROSS1 due to more suitable value of self-declaring probability and D-CROSS1 outperforms the LEACH protocol in network life. It is interesting to note that D-CROSS2 shows good results than LEACH when the number of nodes increases (see Figure7).

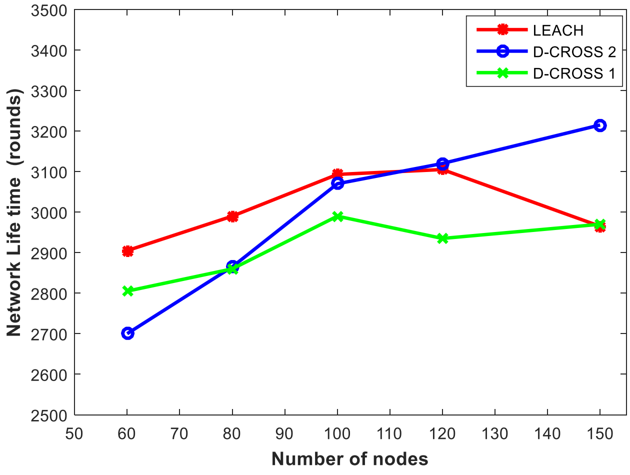

Figure 7: The network lifetime for LEACH, D-CROSS1, and D-CROSS2 for a different number of nodes.

5. CONCLUSION

In this paper, we considered some measures for boosting the effectiveness of sensor nodes and to improve the network lifetime in wireless ad hoc sensor networks. Communication between the nodes is executed by means of a single-hop channel or by using a multi-hop channel. Minimum transmission power assures the improved network lifetime. D-CROSS deals with selection of *CH*, broadcasting the message of *CH* selection, and TDMA base frames allocation to each node for message transfer. By using the simulator, we have found that LEACH protocol is independent of the ω parameter, while the numbers of clusters in D-CROSS are dependent on the value of parameterω. We emphasized on the effect of variation of number of *CH* per round and determined its impact on the network lifetime, the number of alive nodes, and maximum lifetime. The simulation results revealed that D-CROSS performs better than the LEACH protocol in almost every case.

6. AVAILABILITY OF DATA AND MATERIAL

The used or generated data in this study is available by request to the corresponding author.

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