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Research paper

A Game Theory Approach for Efficient Node Clustering Based on Unstable Ranging Transmission in MANET

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Abstract

In Mobile Ad Hoc Network (MANET), improving scalability, energy efficiency and network lifetime are the most important and challenging issues. Node Clustering is a well known solution for handling these issues. While existing work focused on stable transmission range, this paper uses unstable ranges transmission for clustering nodes in network. Game theory has been used in fields of science such as economics and biology, but recently it was used in MANET for clustering problem. Grouping mobile nodes into convenient clusters can reduce routing overhead and provide more scalable solution. The main objective of this work is to clustering of nodes in MANET and selects energy efficient cluster head to improve the network lifetime using game theoretical model. This paper proposes an efficient algorithm for Node Clustering based on Unstable Ranging Transmission (NCURT). In addition to this, a game theory based cluster head (CH) selection algorithm is proposed to selects CH based on Evolutionary game theory approach where each node behaves selfish or unselfish based on the strategy selection. Analytical and simulation studies are carried out to assess the performance of the proposed cluster formation and cluster head selection algorithm. The numerical results verify that the proposed approach is effective and efficient to guarantee life time and energy efficiency in MANET.

Keywords: *MANET, Game theory, Evolutionary approach, Clustering, Transmission Range*.

1. Introduction

A Mobile Ad Hoc Network (MANET) is a set of dynamic self-organizing wireless mobile nodes, which communicate with each other without the need for any existing network infrastructure or federal network management. Each node in network is furnished with a remote transmitter and recipient, which enable it to communicate with other nodes in its radio communication range. The network topology habitually changes because of the portability of mobile nodes as they move inside, move into, or move out of the network. MANET is fit for making a self-arranging and self-maintaining network without the assistance of a centralized infrastructure, which is frequently infeasible in vital mission applications like military conflict or crisis recuperation. One essential issue with consistent support in MANETs is the network lifetime, because the remote terminals are battery fueled, and energy is a rare asset [1].

To enhance the lifetime and energy efficiency of a network, an efficient technique is required to lessen the overheads of the energy. Clustering is an efficient solution to handle these issues. It divides the network into various sub groups based on specific rules. Each cluster has three sorts of nodes: ordinary node (members of cluster), gateway node (non cluster head node with inter-clusters links) and cluster-head [2]. The cluster head is responsible for coordination among the nodes inside its group, and forward the gathered information to the sink node, usually after efficiently aggregating them. The essential operation in clustering is cluster head selection for each cluster.

Some of the clustering and cluster head selection methods in MANET includes location based [3], mobility based [5], neighbor [6], power [7] and weighted based clustering[8]
[9]. These methods contains overhead because of high cluster numbers, limited node coverage, and waste of node energy. To defeat these problems this paper proposes an energy efficient Node Clustering algorithm based on Unstable Ranging Transmission (NCURT). It reduces the number of clusters and covers all the nodes in the network.

Game theory is a mathematical foundation for capturing behavior in intuitive decision situation. It gives a framework and systematic approach for predicting the consequences of complex and dynamic connections between normal agents who endeavor to maximize personal payoff (or reduce private cost) according to strategies of other agents [10]. Because of its interesting and sometimes unpredicted outcomes, its popularity reached the field of communications and networking technology [11]. Recently it has been used for secure routing [12], selfish node detection [13], intrusion detection [14] and monitoring node behaviors [15] in MANET. In this work, the game theory is used to provide the solution for cluster head selection of clustering in MANET. In this paper an evolutionary based game theory approach is used for selecting a cluster head.

The rest of the paper is organized as follows: In section 2 an overview of the related works on clustering, cluster head selection and game theory in MANET is provided. The section 3 describes the new clustering algorithm based on unstable ranging transmission, cluster head selection algorithm based on evolutionary game theory approach are explained, and its evaluation of simulation result is presented in section 4. Finally, section 5 provides the conclusion of the work.

2. Related work

Many network clustering algorithms have been proposed so far in MANET. This section gives an overview of related work on clustering and cluster head selection techniques in MANET.

A weighted distributed clustering algorithm, called CBMD was proposed by Hussein et al., [16]. It contemplates the parameters: connectivity (C), residual battery power (B), average mobility (M), and distance (D) of the nodes to select locally best cluster heads. The objective of this algorithm are maintaining stable clustering structure with a most minimal number of clusters formed, to limit the overhead for the clustering formation and maintenance and to maximize the lifespan of mobile nodes in the system.

Torkestani et al [4] proposed learning automata based weighted cluster formation algorithm MCFA. The parameter of mobility is assigned as a random variable with unknown distribution. The primary purpose of MCFA is to extend the quantity of clusters, cluster life time and re-affiliation time, and to lessen the control message overhead.

A distributed clustering algorithm based on the group mobility and revised group mobility metric was presented in [5]. It is derived from the instantaneous speed and direction of nodes. It use Gauss Markov group mobility model for mobility prediction that permit each node to predict its mobility relative to its neighbors. It is suitable for reflecting group mobility pattern where group partitions and mergence are prevalent behaviors of mobile groups.

In [6] a technique was presented to build multi-hop clusters with reasonable cluster sizes, based on the neighborhood benchmark (NB) to evaluate the availability and link stability of mobile nodes. It produces highly stable multi-hop clusters with low overhead, and gives the adaptability of controlling the cluster radius adaptively for various network applications.

Konstantopoulos et al., [17] predicts the mobility of every mobile host based on the constancy of its neighborhood. This data is then utilized for creating each cluster from hosts that will remain neighbors for adequately extended time, guaranteeing the development of clusters that are highly resistant to host mobility. It includes two factors such as mobility prediction approach and mobility-aware highest degree (MobHiD) technique.

Energy Efficient and Entropy based Clustering for MANET has been proposed in [18]. The cluster formation and cluster head determination depends on a weight factor computed using the battery power, mobility, connectivity components of nodes. The cluster structure acquired from the clustering method is exploited to reduce the energy utilization with increase in the MANET size. It gives improved performance in terms of the network lifetime, energy efficiency and the cluster head determination diminishes the single link failures. Nguyen et al., [19] examine the issue of cluster head selection in two ways: the *distance-constrained selection* where each node in the network must be placed within a certain distance to the nearest cluster head; *the size-constrained selection* where each cluster is only permitted to have a limited number of members. The significant issue of this determination is the management of node mobility and topology changes.

Just couple of research works utilized game theory approach to study clustering for networks. In [22] an energy-efficient ACHGT (Adaptive Clustering Hierarchy based on Game-theoretic Techniques) routing algorithm for WSNs was presented. Each sensor node is considered as player to take a decision for electing a node as cluster head based on the energy consumption. This strategy can keep sensor nodes of lower remainder energy out from being used up quickly.

In [20] a game theoretical modeling of clustering for ad-hoc and sensor networks was provided. It uses non-cooperative game approach to improve the energy and maximize the life time of networks. Dasgupta et al., [21] proposed a Game theoretic approach for choosing a cluster head for every cluster in a WSN. 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. Distance factor and internal energy are used as parameter for cluster head selection. This paper examines the problem of clustering and cluster head selection in MANET. The nodes in the network behave non-selfish, co-operative with others to maximize the energy and life time of the whole network.

3. Methodology

In this section the new proposed node clustering algorithm (NCURT) based on unstable ranging transmission, cluster head selection algorithm based on Evolutionary game theory approach are explained.

3.1 Cluster Formation:

In MANET, the way to partitioning the network into interconnected substructures is called clustering. It is the one of the powerful approach to reduce the energy consumption and enhance the life time of the network. Most of the clustering algorithm use fixed range transmission to group the nodes. This paper utilizes unstable ranging transmission for grouping nodes in a network

Algorithm 1: NCURT

Node Clustering based on Unstable Range Transmission

```
1. Input: Node Position
2. Input: Threshold M;
3. Output: Node_Clusters
4. Initializes Status=Yes; Node_Clusters [0] = All Nodes;
5.  While (Status ==Yes)
6.        Node_Division (Node_Clusters, M);
7.        Node_Fusion (Node_Clusters, M);
8.        LSize=Find_Largest_Cluster(Node_Clusters).size;
9.        If LSize ≤ M
10.             Status=No;
11.       EndIf
12. EndWhile
```

Figure 1 Node Clustering Algorithm

Primarily 25 to 100 nodes are formed in 900 * 600 grid area. The input to the NCURT algorithm is node position i.e. x and y coordinates of the grid and the threshold value M. Any cluster size i.e. number of nodes in cluster exceeds this threshold, that cluster will be further divided into sub-cluster.
Initialize the variable Status as yes, and assign all the nodes to one group to form a single cluster (Step 4). The node clustering algorithm contains two sub algorithms called Node Division (partitioning cluster into sub cluster) and Node Fusion (merging two sub clusters into single one). The algorithm iteratively executes (Step 6-11) these sub algorithms and finds the clusters of node. Find_Largest_Cluster (Step 8), method identifies which cluster contains maximum number of nodes. If the size of largest cluster is less than or equal to threshold M (Step 9) then the iteration will be stopped.

Figure 2 shows the Node_Division Algorithm. In Step 4, the upper bound of cluster (UP) is identified using Find_Largest_Cluster method. The identified UP is further divided into number of sub cluster. This process continues (Step 6-17 in Fig 2) until the size of UP is less than or equal to the threshold M. In Step 6 (Fig 2), the value of transmission range was calculated using eq(1). Randomly select number of nodes in UP, find the nearest neighbors of each node using Euclidean Distance.

$$R = \frac{1}{r}\sum_{i=1}^{r} Euc\_Dist(Nearest\,Neighbor_i) \qquad (1)$$

If the computed transmission range R value is zero then the transmission range will be updated. In Step 10 (Fig 2), the UP is divided into number of temporary clusters (TC) based on the R. The first node in UP is used to create 1st cluster. After that the nearest neighbors was found using Euclidean Distance. If the distance was less than or equal to R then the current node is added to current cluster otherwise new cluster will formed. This process will be stopped when all the nodes in the network covered. If the size of TC is equal to 1 then the again the transmission range R will be changed. This process continues (Step 11-13 in Fig 2) until size of TC will be greater than 1. The UP is removed from the current Node_Clusters (Step 15) and TC will be added to Node_Cluster (Step 16).

Algorithm 2: ***Node_Division***

```
1. Input: Node_Clusters
2. Input: Threshold M;
3. Output: Node_Clusters (Updated Node_Clusters)
4. UP=Find_Largest_Cluster (Node_Clusters) // Upper Bound Cluster
5. While (UP.Node_Count > M)
6.      R=Find the Range for Transmission;
7.      If(R==0)
8.           Continue;
9.      End IF
10.     TC=Temporary_Cluster (UP)
11.     While (TC.size<1)
12.          Change the Range Value
13.          TC=Temporary_Cluster (UP)
14.     EndWhile
15.     Remove UP from Node_Clusters
16.     Add TC to Node_Clusters
17.     UP=Find_Largest_Cluster (Node_Clusters)
18. EndWhile
```

Figure 2 Node Division Algorithm

Figure 3 shows the Node_Fusion Algorithm. This algorithm is used to merge two clusters into single one. The Cluster C_2 is merged with C_1 when the following eq (2) is true.

$$Dist\,(C_1, C_2) + R_1 \le R_2 \qquad (2)$$

Where Dist (C_1, C2) is the Euclidean Distance between Cluster 1 and Cluster 2. R_1 and R_2 are the transmission range of Cluster 1 and Cluster 2.

Algorithm 3: ***Node_Fusion***

```
1. Input: Node_Clusters
2. Output: Node_Clusters (Updated Node_Clusters)
3. For each Ci in Node_Clusters do
4.      Ri=Transmission Range of Ci
5.      For each Cj in Node_Clusters do
6.           Rj=Transmission Range of Cj
7.           If (Dist (Ci, Cj) + Ri ≤ Rj)
8.                Merge Ci and Cj
9.           End If
10.     EndFor
11. EndFor
```

Figure 3 Node Fusion Algorithm

3.2 Cluster Head Selection:

Game theory is increasingly focusing more attention as a mechanism to solve various problems [12-15] in MANET. Generally, a game consists of a set of players, a set of strategies for each player and a set of corresponding utility functions. Generally a game is defined as, G = (N, S, U) where
N = $\{n_1, n_2, \ldots, n_n\}$ is a set of players(nodes in networks). S=$\{s_1, s_2, \ldots, s_n\}$ is the available strategy and U=$\{u_1, u_2, \ldots, u_n\}$ is the corresponding payoff function of node. u_i is the utility value of each node receives at the end of an action.

Evolutionary games have been developed in biological sciences in the aim of studying the evolution and equilibrium behavior (called Evolutionary Stable Strategies – ESS) of large populations. Mutation and Selection is the two important methods of evolutionary process and the evolutionary game. Mutation is the mechanism of modify the characteristics of a player. The mutation mechanism is described by evolutionarily stable strategies (ESS). The selection mechanism is then applied to retain the players with high fitness while eliminating players with low fitness. The selection mechanism is described by replicator dynamics [23].

In this paper, the evolutionary game theory is used to select the cluster heads from set of nodes. The game theory model for the cluster head selection is defined as follows. Game G=(N, M, A, U) where N= $\{n_1, n_2, \ldots, n_n\}$ is the number of nodes in each cluster. M is mode (cooperative, non-cooperative), A= $\{a_1, a_2, \ldots, a_n\}$ is the available action and U=$\{u_1, u_2, \ldots, u_n\}$ is the corresponding payoff function of node, u_i is the utility value of each node receives at the end of an strategy. The utility is computed based on the selected Mode M and Action A.

Table 1 Payoff matrix for two nodes based on Mode

	Node-2		
Node-1	***Mode***	Cooperative	Non-Cooperative
	Co-operative	1, 1	0.5, 0
	Non Co-operative	0, 0.5	0, 0

Table 1 shows the payoff matrix for two nodes based on Mode. If two nodes are in cooperative mode both are get score one. If one node in cooperative mode and another node in non-cooperative mode, then the cooperative node will get 0.5 score, while the non-cooperative node get zero. If both nodes are in non-cooperative the score will be zero.
Figure 4 shows the cluster head selection algorithm based on evolutionary game theory. Initially the utility of each node in each cluster is assigned as zero (line 5). The nodes are inter-acted with other nodes until the each cluster selects its cluster head. (line 9). The node can select any mode cooperative or non-cooperative (line 10). Three types of evolutionary strategy (action) communication, distance and energy will be used for computing node utility (line 11). The term action and strategy are interchangeably used.

Algorithm 4: ***Cluster Head Selection***

```
1. Node Cluster C
2. Cluster Head
3. For each Cluster c ∈ C do
4.     For each Node n ∈ N do
5.         Utc (n) =0;
6.     EndFor
7. EndFor
8. For each Cluster c ∈ C do
9.     While not selected cluster head do
10.        Select m ∈ M (Mode i.e. cooperative || non-cooperative)
11.        For each Action a ∈ A (communication || Distance || Energy) do
12.            if (a = communication)
13.                commUtc=δ*Pc + (1-Pc)
14.            if (a = Distance)
15.                disUtc=δ*Pd + (1-Pd)
16.            if (a = Energy)
17.                EngrUtc=δ*Pe+ (1-Pe)
18.        EndFor
19.        Utc (n) =commUtc+disUtc+EngrUtc
20.        Sort Utc
21.        Select High Utc Node as Cluster Head
22.    EndWhile
23. EndFor
```

Figure 4 Cluster Head Selection Algorithm

The utility value of communication strategy will be calculated as (line 13),

$$commUt_c = \delta * P_c + (1 - P_c) \quad (3)$$

Where $\delta = \begin{cases} 1 & if\ node\ is\ cooperative \\ 0 & if\ node\ is\ non-cooperative \end{cases}$

P_c is the probability of communication and it's defined as,

$$P_c = \frac{n_c}{n_c + n_{nc}} * \frac{n_c}{TN} \quad (4)$$

Where n_c is number of cooperative nodes, n_{nc} is number of non cooperative nodes and TN is total number of nodes in cluster.
The utility value of distance strategy will be calculated as (line 15),

$$disUt_c = \delta * P_d + (1 - P_d) \quad (5)$$

P_d is the probability of distance and it's defined as,

$$P_c = \frac{\min\_dist\ n_c}{\min\_dist\ n_c + \min\_dist\ n_{nc}} * \frac{n_c}{TN} \quad (6)$$

Where min_dist n_c is the number of cooperative nodes that con-tains minimum distance value. min_dist n_{nc} is the number of non-cooperative nodes that contains minimum distance value. The utility value of energy strategy will be calculated as (line 17),

$$engrUt_c = \delta * P_e + (1 - P_e) \quad (7)$$

P_e is the probability of energy and it's defined as,

$$P_e = \frac{\max\_engr\ n_c}{\max\_engr\ n_c + \max\_engr\ n_{nc}} * \frac{n_c}{TN} \quad (8)$$

Where max_engr n_c is the number of cooperative nodes that con-tains maximum energy level. max_engr n_{nc} is the number of non-cooperative nodes that contains maximum energy level.

Based on these utility values the cluster heads are selected for each cluster.

4. Simulation and Result Analysis

Java is used for simulation. The algorithm is simulated for 100 mobile nodes randomly placed on 900 * 600 grid area. Fig 5 shows the node deployment. The initial transmission range of nodes is assumed to be 100. The initial battery power of nodes is fixed uniformly to 100 units.

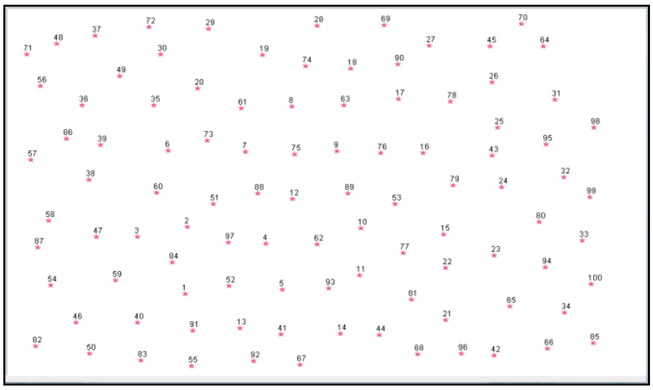

Figure 1 Node Deployment

The nodes are clustered using unstable ranging transmission. Fig 6 shows the cluster formation of nodes. Each cluster has different transmission range. The transmission range was calculated using eq (1).

Table 2 Transmission Range for each cluster

Cluster Id	Transmission Range
C-1	197
C-2	213
C-3	205
C-4	186
C-5	206
C-6	182
C-7	190
C-8	159

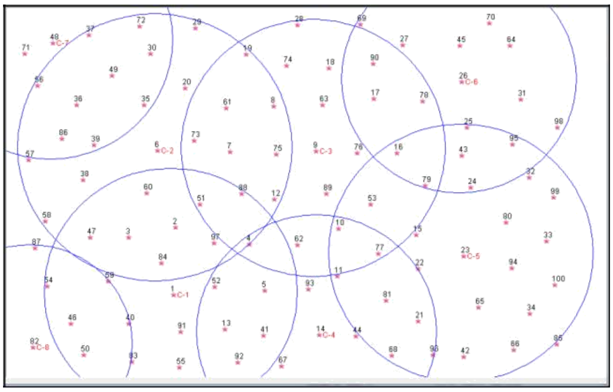

Figure 6 Cluster Formation

Figure 7 shows the cluster head selection. The cluster heads are selected based on evolutionary game theory approach. In selection process, the node can be in cooperative or non-cooperative mode. The utility value of each node can be calculated using three actions i.e. communication, distance and energy. Based on these actions the cluster heads are selected.

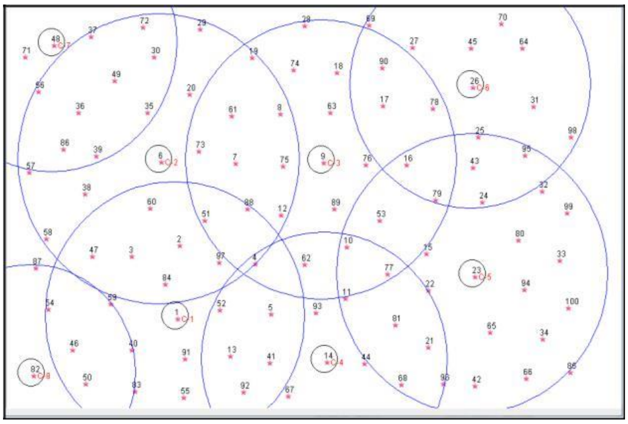

Figure 7 Cluster Head Selection

Table 3 No of Nodes Vs Cluster Size

	Cluster Size	
No of Nodes	**Unstable Range**	**Stable Range**
20	4	6
40	5	12
60	7	14
80	7	15
100	8	15

Table 3 shows the cluster size for unstable and stable range for different number of nodes. Figure 8 display the graph of cluster size for different number of nodes. Cluster size is increased for stable range.

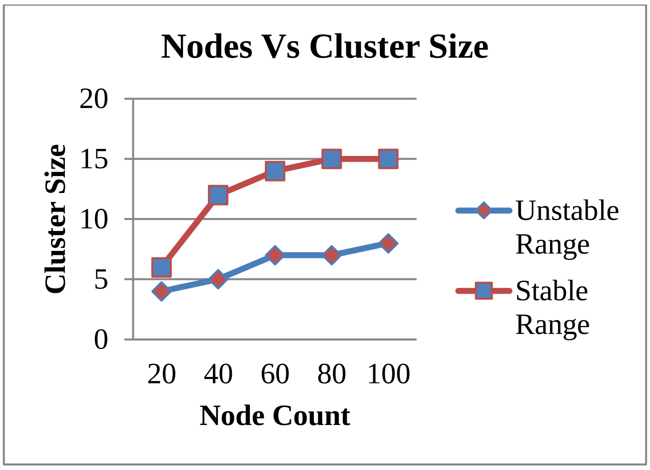

Figure 2 Nodes Vs Cluster Size

Figure 9 shows the network life time based on stable and unstable transmission range.

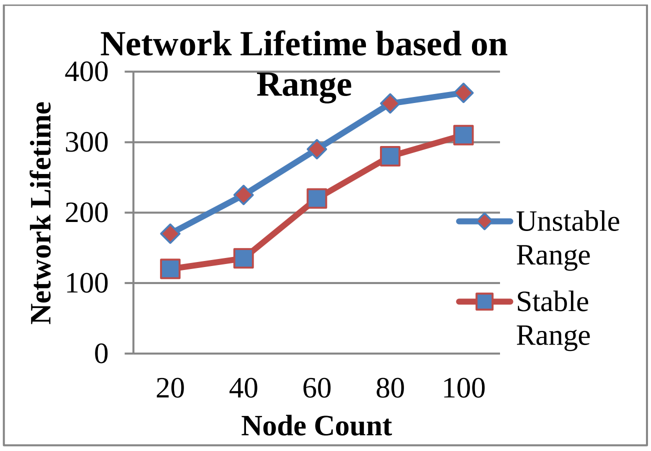

Figure 3 Network Lifetime based Range

The most important metric that reveals the performance of any clustering technique is the network lifetime. Fig. 10 shows the network lifetime for various number of sensor nodes for the CROSS [20], CoPA [24] and the proposed NCURT + Evolutionary game. Network lifetime is defined as 'the lifespan of the node that first among all the others deplete its energy' [20]. The proposed work achieves longer lifetime than the other two for any number of nodes.

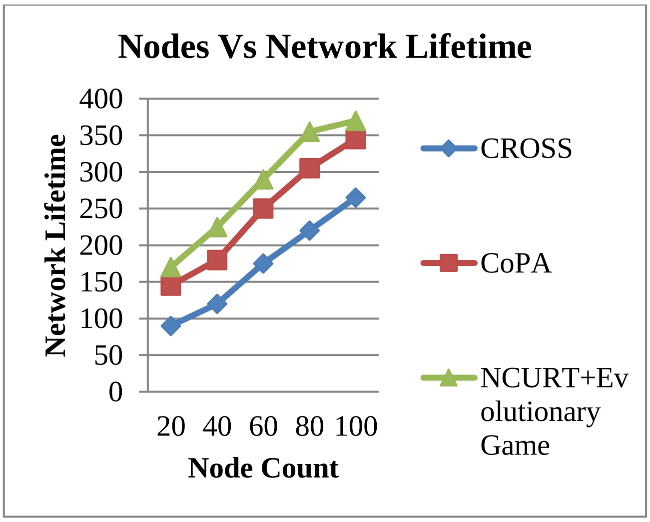

Figure 4 Network Lifetime Comparison

5. Conclusion

This paper exhibited a clustering algorithm based on unstable ranging transmission called NCURT. This algorithm is able to produce efficient clusters. This paper proposes a strategy for cluster head selection using game theoretical approach in MANET. This paper designs an evolutionary game to analyze the behaviors and strategies of the network nodes. In this evolutionary game every node has compute its utility value based the actions they selected. Based on the utility value, cluster heads are selected for each cluster. Finally, extensive simulation results show that NCURT and evolutionary game approach gives an effective and efficient to guarantee life time and energy efficiency in MANET.

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