A Coalition-Formation Game Model for Energy-Efficient Routing in Mobile Ad-hoc Network

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ABSTRACT

One of the most routing problems in Mobile Ad-hoc Network is the node's selfishness. Nodes are generally selfish and try to maximize their own benefit; hence these nodes refuse to forward packet on behalf of others to preserve their limited energy resources. This selfishness may lead to a low efficiency of routing. Therefore, it is important to study mechanisms which can be used encourage cooperation among nodes, to maintain the network efficiency. In this paper, we propose a cooperative game theoretic model to support more energy-aware and available bandwidth routing in MANET. We introduce a novel framework from coalitional-formation game theory, called hedonic coalition-formation game. We integrate this model to OLSR protocol that is an optimization over the classical link state protocol for the MANETs. Within each coalition, a coalition coordinator acts as a special MPR node to improve the energy efficient and the packet success rate of the transmission. Simulation results show how the proposed algorithm improve the performance in terms of the percentage of selected MPR nodes in the network, the percentage of alive nodes by time, and the Packet Delivery Ratio. Which prove that our proposed model leads, to better results compared to the classical OLSR.

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1. INTRODUCTION

Due to the recent emergence of large-scale, distributed and heterogeneous communication systems which are continuously increasing, next generation wireless networks will present a highly complex and dynamic environment. One class of such networks is Mobile Ad-hoc Network (MANET). In MANET, autonomous mobile nodes are deployed across the zone of a network. The mobility of the devices is infrastructure-less and lacks any permanent topology. One of the crucial tasks in MANET is routing, since the network is in general multi-hop, a routing protocol is needed in order to discover and maintain routes between far away nodes, allowing them to communicate along multi-hop paths. In particular, energy efficient routing may be the most important design criteria for MANETs, since mobile nodes will be powered by batteries with limited capacity. Power failure of a mobile node not only affects the node itself but also its ability to forward packets on behalf of others and thus the overall network lifetime. The nature of infrastructure-less communication in MANET necessitates engagement nodes to cooperate to keep the network performance. However a network node has no interest in forwarding a packet on behalf of another node since this action would only have the effect of consuming its energy and available bandwidth. This selfishness may lead to a low efficiency of routing in MANET. Moreover, to some nodes that are willing to forward data packets for others, their energy may be depleted within a short period of time, and potentially bring the whole network down.

In order to cope with this problem, several research activities to encourage nodes to cooperate have been recently proposed. The main approach considered is to give nodes some incentive for packet forwarding. Most of the existing work, to motivate nodes in ad hoc network to cooperate, can be divided into two main classes: credit-based and reputation-based. In credit-based systems [1-3], nodes uses virtual currency to pay for obtaining relay services, so nodes must obtain sufficient credit by providing service to other nodes. In reputation-based systems [4-7], nodes track the cooperation behavior of other nodes and use it to decide how much service to provide to them. However, it’s very difficult to adopt such a motivating mechanism for MANET. So the more appropriate tool for handling the forwarding behaviors in MANET with selfish nodes is game theory [8]. Examining cooperation in wireless ad hoc networks using game theory gives a more comprehensive perception of the process [9].

In this work, we define a cooperative game theoretic model to support more energy-aware and available bandwidth routing in MANET. In non-cooperative games, nodes act independently to enhance their own interests, while nodes in cooperative games may agree to form coalitions and make decisions based on collaborative strategies. We introduce a novel framework from coalitional-formation game theory, called *hedonic coalition-formation* game. Hedonic games have been widely used in game theory, especially in economic and political sciences fields. To the best of our knowledge, utilization of this framework in MANET has not been studied thoroughly. The proposed model adopts reachability with minimum overhead cost as a measure of the benefits of cooperation, and an appreciation of the re-transmission expenditure to evaluate the cooperation cost. After the coalition formation process reaches the steady state, we are interested in the stability of the formed coalitions. We integrate this model to OLSR protocol that is an optimization over the classical link state protocol for the MANETs. The effect of mobility on network topology is a key challenge in coalition formation. To prove the efficiency of our proposed approach, we simulate MANET with variant number of nodes. The simulation results show that our proposed model, based on coalitional formation game, can efficiently prolong the network lifetime.

The remainder of this paper is organized as follows. Related work is summarized in Section 2. System model and proposed algorithm are discussed in the Section 3. Simulation environment and results are presented in Section 4, and conclusion is articulated in Section 5.

2. RELATED WORK

The problem of designing efficient protocols for MANET has received significant attention by the research community for over a decade. Many efficient schemes have been developed. In [10] the author showed the pefromance of 802.11 MAC on basis of broadcasting traffic load using random waypoint model In MANET. He aimed to show effictive performance of constant bit rate based on broadcasting data from one network to other network. In [11] the authors modeled a rushing attack which is a powerful attack that exploits the weaknesses of the secure routing protocols in MANET, in order to know the weakness and strength of these protocols, it was necessary to test their performance in hostile environments. Subsequently, the performance was measured with the various metrics, some of them are average throughput, packet delivery ratio, and average end-to-end delay, to compare and evaluate their performance.

In the last decade, much attention has been dedicated to game theoretical game models for wireless ad hoc network in general and for cooperation mechanisms precisely [12-14]. These works investigate multiple subjects concerning cooperative games, fair payoff allocation and trust models. The proposed works in cooperative games relying incentive mechanisms can be divided into two major classes: credit-based [1-3] and reputation-based [4-7]. Moreover many presented works adopt game theoretical models as a base of their proposed approach for enhancing packet forwarding in wireless ad hoc networks [15], [16]. The discrepancy between the benefit from cooperation and the required cost for cooperation prompts the researchers to adopt game theoretic models, where each player strategically decides, based on his payoff, to participate for the common good of the set or not. The players in game theory try to maximize an objective function that takes the form of a payoff. Players choose strategic actions and each player's payoff depends not only on his own action, but also on those of the other players. The global purpose of these games is to attain an equilibrium state where every player is satisfied and no participant wants to modify its cooperation choice. There are two main types of theoretical game: non-cooperative games and cooperative games. In non-cooperative games, each node has to select a strategy so as to maximize its own benefits by taking the suitable actions [17], [18]. In cooperative games, nodes must first decide whether or not to join a coalition that share common benefit [19-21].

In [22] Manam and Mahendran have investigated an analytical method to evaluate the effectiveness of some routing protocols considering that consists of selfish nodes that have different ranges of transmission. However Wang and Singhal in [23] have proposed a novel routing algorithm for MANETs with selfish nodes. They present a protocol using a motivating mechanism to promote cooperation among nodes, their proposition concentrate on the truthfulness. Watchdog and pathrater are proposed in [24] to identify misbehaving nodes and deflect traffic around them. Reputation-based protocols are proposed in [25], [26].

In cooperation based on the notion of coalitional game theory [27], subgroups of nodes combine their forces and decide to act together, so that this formed coalition gives the optimum payoff. Therefore the formed coalitions should keep their stability. A coalition is stable if no node has an incentive to move from its current coalition to another or to deviate and act alone. However in MANETs, nodes may be obliged to quit their coalition due to topological changing condition caused by mobility.

In [28] Omrani and Fallah investigated the concept of core in coalition game theory to discover a stable payment model for nodes that participate to forward packet on a cost efficient path. They set a fixed time slot as the duration of time in which nodes in the network do not change their positions, so that in this duration of a stable time slot, a node is able to find out the complete topology of the network. However this procedure could be useful in small networks with low mobility speed, but with a considerable mobility speed, this procedure has less efficiency.

In [29] Cai and Pooch proposed an approach to increase the network lifetime by motivating nodes to collaborate to enhance the transmission power that allows delivering packets over shared routes. They adopt the notion of the shapely value to allocate the cooperation payoff fairly among the nodes which belong to a same coalition in MANET like as the forwarding cost is balanced over them.

3. THE COMPREHENSIVE THEORETICAL BASIS AND PRPOSED METHOD

3.1. Problem Description

An ad hoc network is modeled as a directed graph $G = (V, E)$, where V and E are the set of nodes and the set of directed links respectively. Each element in E denotes that two nodes are within the radio range of each other. Nodes in the network are battery-powered and have limited computation and wireless communication capabilities. A node may be connected with several nodes nearby through wireless communication. Each node in a MANET is moving dynamically with its own track. Nodes in a MANET will generate data packets periodically and try to send out generated data packets to some destinations.

Some nodes in MANET behave with selfishness, since they want to maximize their benefits with least cost to conserve their energies as much as possible during the routing process, which can affect the entire network if many nodes behave like that. However, it is required for nodes to forward data packets in order to benefit the overall network. To overcome this problem, we have proposed a new framework that allows investigating the problem of energy-efficiency routing in OLSR protocol by modeling it as a coalitional game theory, as each player in a cooperative game, the nodes attempt to combine their forces and decide to act together, so that this formed coalition gives the optimum common payoff.

3.2. Brief Review of OLSR Routing Protocol

OLSR (Optimized Link State Routing), [30], is a proactive routing protocol where nodes periodically exchange topology information in order to establish a route to any destination in the network. It is an optimization of a pure link state routing protocol, based on the concept of multipoint relays (MPRs). First, using multipoint relays reduces the size of the control messages: rather than declaring its entire links in the network, a node declares only the set of links with its neighbors that have selected it as "multipoint relay". The use of MPRs also minimizes flooding of control traffic. Indeed only multipoint relays forward control messages. This technique significantly reduces the number of retransmissions of broadcast messages. OLSR consists of two main functionalities:

a) Neighborhood discovery. Each node acquires the knowledge of its one-hop and two-hop neighborhood by periodic Hello messages. It independently selects its own set of multipoint relays (MPRs), among its one-hop neighbors in such a way that its MPRs cover (in terms of radio range) all its two-hop neighbors.

b) Topology dissemination. Each node also maintains topological information about the network obtained by TC (Topology Control) messages, broadcast by MPR nodes.

Each node computes its routing table by the Dijkstra algorithm. This table provides the shortest route (i.e. the route with the smallest hop number) to any destination in the network.

3.3. Hedonic Coalition Formation Game

In this section we introduce those concepts of hedonic coalitional formation game used in our proposed scheme.

Hedonic coalitional formation games entail several interesting properties that can be applied, not only in economics and politics, but also in wireless ad hoc networks as we will define in this work. A coalition formation game is called to be *hedonic* if the gain of any player depends solely on the members of the coalition to which the player belongs, and the coalitions form as a result of the preferences of the players over their possible coalitions' set.

Before discussing the application of hedonic game in our proposed scheme, we give some definitions, taken from [31].

Definition.1: A *coalition structure* or a *coalition partition* is defined as the set $\Pi = \{S_1, \ldots., S_l\}$ which partitions the players set *N*, i.e., $\forall K \;, S_k \subseteq N$ are disjoint coalitions such that $U_{k=1}^{l} S_k = N$.

Definition.2: Given a partition Π of *N*, for every player $i \in N$ we denote by $S_\Pi(i)$, the coalition $S_k \subseteq \Pi$, such that $i \in S_k$.

In a hedonic coalition formation game framework, every player has to build preferences over its own set of possible coalitions, in order to be able to choose which coalition he prefers being a member of. For evaluating these preferences of the players over the coalitions, we define the concept of a preference relation or order as follows [31]:

Definintion.3: For any player $i \in N$, a *preference relation* or *order* $\succeq_i$ is defined as a complete, reflexive, and transitive binary relation over the set of all coalitions that player i can possibly form, i.e., the set $\{S_k \subseteq N : i \in S_k\}$.

Hence for a player $i \in N$, if there are two coalitions $S_1 \subseteq N$ and $S_2 \subseteq N$ such that $i \in S_1$ and $i \in S_2$, $S_1 \succeq_i S_2$ means that player i prefers to be part of coalition S_1, over being part of coalition S_2. The preference relation can be a function of many parameters, such as the payoffs that the players receive from each coalition.

A hedonic coalition formation game is formally defined as follows [31]:

Definition.4: A hedonic coalition formation game is a coalitional game that satisfies the two hedonic conditions previously prescribed, and is defined by the pair $(N, \succ)$ where N is the set of players, and $\succ$ is a profile of preferences, i.e., preference relations $(\succeq_1, \ldots, \succeq_{|N|})$ defined for every player in N.

3.4. System Modeling

After introducing the main concepts of hedonic coalition formation games, we adopt this framework in order to propose a suitable solution for the energy aware problem in MANET. Hence the MANET routing behavior is modeled as a $(N, \succ)$ hedonic game, where N is the set of nodes in the network, and $\succ$ is a profile of preferences that we will define.

To assess nodes performance, a weight is assigned dynamically to each node (W_i), which takes into account cross layer parameters; these parameters include network congestion, residual energy of mobile nodes, as well as, network topology parameters. We combine these metrics with some multiplicative factors to compute a weight for each node i, as shown in Equation (1).

$$W_i = \alpha_1 * RE_i + \alpha_2 * N_1(i) + \alpha_3 * (1 - \frac{NP_i}{MQ_{max}}) \quad (1)$$

Where $\alpha_1 + \alpha_2 + \alpha_3 = 1$, RE_i is the residual energy at each time, $N_1(i)$ is the number of nodes that belong to one-hop neighborhood of i, NP_i is the number of packets in the MAC queue and MQ_{max} is the maximum considered MAC queue size of i. By varying the weighting factors, we can change the importance of the three metrics. For our experiments, we gave $\alpha_1 = \alpha_2 = \alpha_3 = \frac{1}{3}$.

The first modification we made in OLSR structure is to embed the nodes' weight value to the Hello messages that are periodically generated by each node. So Hello packet is extended to include a field for the updated weight. In order to partition the network into coalitions and define a set of optimal *coalition coordinator* (CC), each node declares its neighbor which has the maximal weight value. A node can also declare itself, if it has the maximal weight value. The nodes use their Hello messages to broadcast their declarations. Hence we have one-hop coalitional model, each node is one-hop away from its designated coalition coordinator.

After defining the coalition coordinators, each coordinator would act as MPR nodes for its coalition members. Hence, these coalition coordinators should broadcast Hello messages that include their coalition members in their MPR selector set. Some other modifications must be done to the Hello structure. We add an indicator that a node has been declared as a coalition coordinator, a second indicator that a neighbor has been declared as a coalition coordinator. The results of the coalition coordinators declarations must be propagated to all the neighbors.

In this case there are two types of communication, intra-coalition communication and inter-coalition communication. In the intra-coalition communication, inside the coalition the coalition coordinator can directly communicate with every member node. In order to enhance energy consumption, only the coalition coordinator is continuously on active mode, and the members which are not working are kept on sleep mode.

Hence if any node wants to send a packet to one of sleeping nodes, it can just forward it to the coalition coordinator that send an acknowledgement to the destination, and it changes its mode to active mode to receive the packet, after finishing their communication it will again come on sleep mode. However in the inter-coalition communication, forwarding packets between any source-destination nodes will be done by means of their coalition coordinators, the coalition coordinator of the source nodes use the concept of MPR to forward the packet to the destination's coalition coordinator, which would minimize the congestion by reducing the number of forwarding nodes.

For modeling the MANET routing behavior as a hedonic coalition formation game, the preference relations of the players have to be defined. So we define a preference relation indicating the preference of nodes. We assume that the preference relation is common for all nodes in the network N, hence we denote it by $\succeq_i = \succeq_N, \ \forall i \in N$. The preference of any node $i \in N$ is giving as shown in Equation (2).

$$S_1 \succeq_N S_2 \Leftrightarrow v(S_1) \geq v(S_2) \quad (2)$$

Where $S_1 \subseteq N$ and $S_2 \subseteq N$ are two coalitions that the node i is a one-hop neighbor with their coalition coordinator, (in principle i is a member of the coalition that its coalition coordinator had the highest weight at declaration coordinator time). And $v: 2^{|N|} \rightarrow \mathbb{R}$ is a preference function defined as follows:

$$v(S) = W_{cc}(S) \quad (3)$$

Where $W_{cc}(S)$ is the coalition coordinator's weight of the coalition S. By using the defined preference relation, the players can compare two coalitions S_1 and S_2 to choose which one to be member in. regarding to this model, being a coalition coordinator, obligates this player to act as a common MPR for the other members, however the ordinary members have to provide forwarding services for any packet sourced by the coalition coordinator. The payoff that a node receives by being in a coalition is the number of nodes that can reach intra-coalition and inter-coalition by means of one MPR node (CC), hence this approach is able to prolong the network lifetime by reducing the percentage of MPR nodes which eventually reduces the traffic overhead and channel collisions, moreover the energetic conservation by passing to sleep mode.

4. RESULTS AND ANALYSIS

In this section we will describe the simulation setup and results used to evaluate our modified version of OLSR (with coalition formation) compared to the classical one, by means of NS3 network simulator. We considered three performance metrics to evaluate this proposition, which are:

a. The percentage of selected MPR nodes in the network.
b. Nodes lifetime: the percentage of alive nodes by time.
c. Packet Delivery Ratio (PDR): the ratio of the number of packets delivered to the destination nodes over the number of packets sent by the source nodes.

We simulated a MANET with a variant number of nodes, within a 800 x 800 meter square area, the size of generating packets is 1024 bytes, mobile nodes move in the area based on a Random Waypoint mobility model with maximum speed of 15 m/sec, the simulation time is set to 400 seconds. The simulation parameters are summarized in Table 1.

Table 1. Simulation Parameters

Area	800m x 800m
Nodes	40, 60, 80, 100, 120
Traffic Type	CBR / UDP
Packet Size	1024 bytes
Start of Traffic	50 seconds
Transmission Power	10 dbm
Link bandwidth	2 Mb/s
Initial Node Energy	0.4 Joules
Simulations/Scenario	4 times
Nodes' speed	15 m/sec
Simulation time	300 seconds

We simulated a MANET with variant nodes' number, we aimed to assess our proposed algorithm from overhead point of view, by comparing the percentage of selected MPR nodes in the network, the percentage of alive nodes by time, and PDR between modified and standard OLSR.

As shown in Figure 1, the OLSR with coalition formation obviously minimized the number of selected MPR nodes. Because these MPRs contain the coalition coordinators, that behave as special MPR nodes. So the ordinary MPRs are selected by a lessen number of nodes (coalition coordinators) than in standard OLSR. Thus the coalitional formation model would minimize the network congestion due to the considerable number of control message that be avoided, hence it would be more convenient for dense networks. By our protocol model there is a decreasing of about 22% of MPR nodes compared to the standard OLSR.

Figure 2 shows that our modified protocol outperform the standard one in prolonging the network lifetime, first because we have less number of MPR nodes which eventually reduces the traffic overhead and channel collisions, and the second reason is the fact that keeping nodes in sleep mode when there is no forwarding service to do, which reduce significantly the energy consumption of nodes. Moreover, our modified scheme achieves more uniform utilization of network resources by adopting the residual energy cost and MAC queue utilization cost of each node when declaring the coalition coordinators.

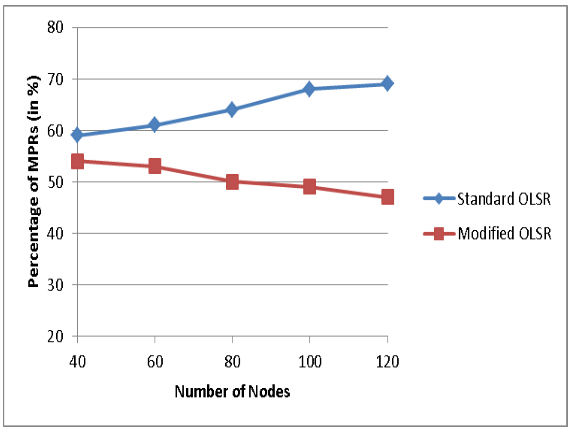

Figure 1. Percentage of MPR nodes

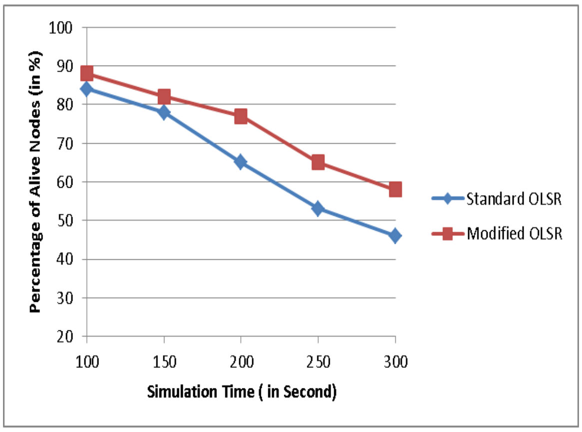

Figure 2. Percentage of Alive nodes

The packet delivery ratio is one of the important aspects that we consider in our proposed scheme. In Figure 3 We can observe that PDR has an improvement reach to up to 4% in the case of our formation model OLSR, due to the fact queue utilization is taken in consideration as important criteria in computing the weight for nodes, based in, nodes declare coalition coordinator that act as a specialized MPRs, thus our model gives a priority to nodes that less congested to be coalition coordinators, because, as known, the congestion in nodes queue is the most cause of packet losing. This causes this slight improvement in PDR.

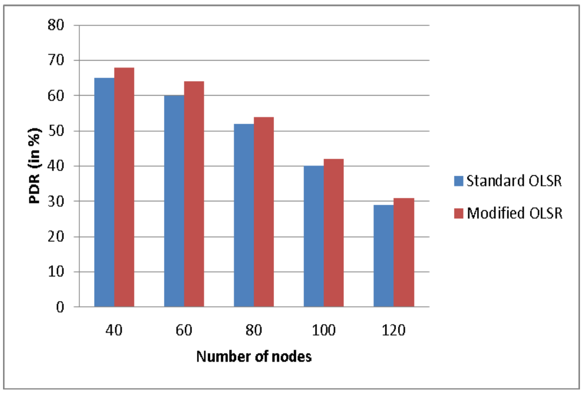

Figure 3. Packet delivery Ratio

In summary, after have analyzing the previous results, we can conclude that the coalitional formation model of OLSR protocol has more chance to extend network lifetime due to its propriety to select less number of MPRs, hence minimizing the traffic overhead and channel collision, and encouraging cooperation in the network. Moreover this model takes in consideration energy efficiency while choosing the MPRs, which has a large impact on the network lifetime.

5. CONCLUSION

In this paper, we introduced a cooperation model in MANETs based on coalitional formation game theory. In the proposed model, the nodes in MANET are required to collaborate among them to efficiently forward packets during routing process in the network, the MANET routing behavior is modeled as a hedonic coalition formation game among nodes in order to form disjoint coalitions. To form the coalitions, we adopt an algorithm that allows declaring a coalition coordinator by neighbor nodes based on cross layer parameters; these parameters include network congestion, residual energy of mobile nodes, as well as, network topology parameters, then the ordinary nodes would join or leave the coalitions base on their preferences. We integrate this model to OLSR protocol, where the coalition coordinators act as special MPRs. Moreover, we compare between our modified OLSR with coalition formation and the standard one. Simulation results show how the proposed algorithm improve the performance in terms of the percentage of selected MPR nodes in the network, the percentage of alive nodes by time, and the Packet Delivery Ratio. Which prove that our proposed model leads, in general, to better results compared to the classical OLSR protocol.

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