Analysis the Cooperation Strategies in Mobile Ad hoc Networks

Ze Li, Haiying Shen
Department of Computer Science and Computer Engineering
University of Arkansas, Fayetteville, AR 72701
{zxl008, hshen}@uark.edu

Abstract

In mobile ad hoc network, all the packets are forwarded in a multi-hop fashion relying on the contribution of each participants. In order to encourage the cooperation between the nodes in the system, many incentive mechanisms have been proposed. Although these incentive schemes can improve the cooperation to some certain extend, they are still suffering from some drawbacks. In this paper, the efficiency of these incentive mechanisms has been analyzed based on some game theory modules and their performance has been compared with the proposed cooperation enforcement mechanism assuming that all the mobile nodes are rational. The simulation and theoretical results show the superiority of the incentive scheme of ARM over reputation based scheme and price-based scheme.

1. Introduction

A mobile ad hoc network (MANET) is a self-organized network formed by a collection of mobile nodes without fixed infrastructure management. The packets in the MANET are forwarded in a multi-hop fashion, requiring the contribution of every participant nodes. Recent research shows that the short distance transmission feature of MANET can improve the traditional cellular network in terms of throughput, delay and power efficiency [3]. However, since the mobile nodes in this network are constrained with limited resources, such as CPU, battery, channel bandwidth and etc, some nodes in the network might not be willing to cooperate with the packet transmission, in order to save their resources. Although if the network is under the control of a single authority, such as military monitory, or disaster recovery, the nodes can cooperate without caring for their own benefit. However, as the MANET is predicable to be deployed for civilian application [13, 11, 8, 17, 23] in which no single authority existing for the packets transmission management, the cooperative behaviors between these nodes can not be guaranteed. There might be some nodes that intend not to forward packets to save resources for their own use. The presence of only a few misbehaving nodes can dramatically degrade the performance of an entire system [4]. Two types of uncooperative nodes might exist in the system: malicious nodes and selfish nodes. However, in this paper mainly focuses on the selfish nodes since such kind of nodes is the dominant type of nodes in a civilian ad hoc network [24].

Quite a few proposals have been made to provide incentive to the cooperation in MANET. They can be divided into two main categories: reputation-based schemes, pricing-based schemes. Reputation-based schemes [4, 15, 5, 10, 2] let each node hold a reputation table recording the reputation of other nodes, and exchanges information with neighbor nodes. A node selects routing path according to node's reputation value. Meanwhile, most of the reputation systems set up a reputation threshold. Nodes whose reputation value are higher than the threshold are regarded as cooperative nodes, while nodes whose reputation values are lower than the threshold are regarded as selfish nodes. Nodes provide services to high-reputed nodes, and refuse to provide services to low-reputed nodes. Therefore, as long as a node has a RV that just a little higher than the threshold, it can always be served. This is not fair to high-reputed nodes with different reputation levels since they receive the service with the same quality. Reputation-based schemes need to have a complement method to help them wisely punish selfish nodes, and reward altruistic nodes.

Pricing-based model [12, 6, 7, 24] treats packet forwarding as a service that can be priced, and introduce some form of virtual currency to regulate packet forwarding relationships among different nodes. However, traditional methods that include "virtual currency" in the transmitting packets requires a fair amount of computation and storage resources. Although Sheng and *et al.* in [24] proposed a receipt based method to cope with the selfish behavior in the system. However, since the receipts should be recorded in the whole transmission path and the price paid by the source node depending on the length of transmission path, such method is not suitable for a high dynamic MANET. In addition, these nodes fail to provide a way to know the service quality of a node. Moreover, the implementation of "virtual currency" and "virtual bank" make them much more complex with high requirements on overhead, security and topology.

Other than using incentive mechanisms to encourage the cooperation in MANET, many researchers consider cooperation of entities as the Iterated Prisoner's Dilemma (IPD) game [21] [16, 19, 9, 22]. Since the mobile nodes in the MANET can be treated as distributed and independent rational entities, IPD can provide a collection of forwarding strategies to achieve the best benefit of the system.

However, as far as we know, these three mechanisms are developed individually, no further research has been done to see how these mechanisms mutual affect each other. Since the nodes in the MANET are all self-interested nodes, they are trying to reach a Nash Equilibrium in the system. Thus, the game theory can be a strong foundation to build an effective and stable incentive scheme to encourage the cooperation in the MANET. In this paper, based on some game theory models, drawbacks of traditional reputation system and price-based system are analyzed. Their incentive efficiency are also compared with our previous proposed cooperation enforcement mechanism: The hybrid Reputation Management mechanism (ARM) [18]. ARM is a hierarchical reputation system integrated with a global reputation management reputation system and a pricing-based model for effective selfish node punishment. Reputation system is used to collect reputation value of the mobile nodes, based on which the price is charged for the packet forwarding. This paper has two contributions. First, the incentive efficiency of traditional price-based system and reputation system are analyzed in the game theory fashion. Second, after identifying the limitation of the previous systems, ARM incentive mechanism are analyzed and simulated to demonstrate its superior incentive efficiency.

The remainder of this paper is organized as follows. Section 2 provides related works for encouraging nodes cooperation in MANET. In section 3, we demonstrate how does ARM promote the incentive for the mobile nodes cooperation encouragement. section 4 presents the analysis and simulation results of the performance of ARM in iterated Prisoner's Dilemma (IPD) game Section 5 concludes the paper.

2. Relative works

Three classes of approaches are proposed to encourage the cooperation between mobile nodes in MANET.

One of them is based on a reputation system which gathers reputation value for each node's trustworthiness based on the evaluation from others [14, 15, 5, 10]. Marti [14] proposed two techniques, *watchdog* and *pathrater*. The *watchdog* in a node promiscuously listens to the transmission of the next node in the path in order to detect misbehavior. The *pathrater* in a node keeps the rating of other nodes to avoid any kind of interaction with uncooperative nodes in the transmission. Core [15] uses the *watchdog* technique and weighs heavily towards past reputation to avoid mistaking cooperative nodes with low battery condition as misbehaving nodes. CONFIDANT [5] detects misbehavior nodes and sends alarm messages to other nodes to isolate misbehaving nodes. Wu and Khosla [10] use the first-hand reputation and second hand reputation to calculate the total reputation of a node. The first-hand reputation of each node is periodically updated and broadcasted to its neighbor when the value is dramatically changes. Anantvalee and Wu [1] introduce a new kind of node which is a suspicious node. The suspicious nodes will be further investigated and if they tend to behave selfishly by a two thresholds to reputation system. However, all these methods only use threshold to distinguish the selfish node. A node can wisely maintain their reputation value above the threshold by selectively forwarding packets.

Another approaches is based on a price-system by using virtual currency, credit or micro-payment [12, 6, 7, 24]. Buttyan and Hubaux [6] use a virtual currency called nuglets to pay for the packet forwarding. Two payment models: packet purse model and packet trade model are proposed by them. In the former, a source node pays relay nodes by storing virtual cashes in the packet-head. Intermediate nodes acquire some nuglets from the packet when they forward it. In the latter, a relay node buys packets from the previous node and sells them to the next node in the path for more virtual cashes. The destination node will eventually pay for these transmission. The credit-based system in [24] uses credit clearance service and message receipts to deal with the selfish nodes in the system. When a node receives a message, the node keeps a receipt of the message and uploads it to the credit clearance service for credits. Although the price system provide a new incentive to the packets forwarding, that is the system increase the payoff of cooperation in the view of game theory, however it can not effectively alleviate selfish behavior when some nodes already have gained a consider amount of virtual credits and they do not want to the cooperate any more.

The third approaches tries to encourage the cooperation between the nodes without incentive mechanisms. They try to model these rational and self-interest nodes with some complex nodes' cooperation strategy in a repeated game theory model. Srinivasan in [19] uses the generous TIT-For-TAT mechanism as a node's strategy in a repeated game for forwarding packets. They also derives a social optimal Nash Equilibrium for that. In [9], Felegyhazi and *et al* propose a model based on game theory and graph theory to investigate equilibrium conditions of packet forwarding strategies.

3. Analysis of the Incentive Strategies

3.1 Overview of ARM

In order to encourage the cooperation between the nodes in the ad hoc networks, ARM builds a hierarchical structure to efficiently manage the reputation value of all nodes, and release the reputation management load from individual high mobility nodes. This enables low-overhead and fast global reputation information accesses. The basic idea of incentive scheme of ARM is to intelligently integrate reputation system with pricing-based model to avoid selfish nodes. Rather than just using threshold to detect selfish nodes, which treats equally to the reputed nodes with different reputation values, ARM use price-modal in which the service price of each node is charged based on its reputation value in order to avoid discourage of cooperation of high reputed node. Meanwhile, the reputation value of each node is still used to distinguish the selfish node and cooperative node based on a reputation threshold to encourage the “wealthy” node or “less transmission request” node to take part in the cooperation. More specifically, in ARM, in order to simulate all the nodes to cooperate in packet forwarding, based on the reputation value, every node need pay price for the packet forwarding. A node with higher reputation value need pay less price for the packet forwarding. While the nodes with low reputation should pay much more for the packet forwarding. Therefore, ARM can effectively prevent some selfish nodes from manipulating their reputation value just above some threshold value. ARM can also encourage the nodes with a large sum of virtual cash to continues to engage in the packet forwarding to gain a high reputation. The next several sections are used to show the significant performance of ARM according to the game theory model.

3.2 Game Theory Model

Game Theory is a field of applied mathematics that describes and analyzes interactive decision situations. It provides analytical tools to predict the outcome of complex interactions among rational and self-interest entities who always try to reach a best outcome [20].

The game theory model for the MANET is defined as follow: Given a normal form of game G, $G =< N, A, \{u_i\} >$ where $N = \{1, 2, ..., n\}$ is a set of mobile nodes in a routing path, A_i is the action set for each node i, and A is the Cartesian product of the sets of actions to each node. In the MANET, every node has two action, i.e. cooperate or incorporate. $\{u_i\}$ is the set of utility functions that each node i wishes to maximize. For every node i, the action chosen by node i is denoted as a_i, and the actions chosen by other nodes are denoted as action set $\mathbf{a_{-i}}$, that is $\mathbf{a_{-i}} = \{a_1, a_2, a_3, ...a_{i-1}, null, a_{i+1}, ..., a_n\}$. Every node does not know what actions the others nodes will adopt. We denote $(\mathbf{a_{-i}}; a_i) = \{a_1, a_2, a_3, ...a_{i-1}, a_i, a_{i+1}, ..., a_n\}$ as the action set that all the nodes on a path are adopted at one interaction. That is, the actions they adopt for a certain packet’s transmission. If there is one node chooses incorporation, the packet will be dropped. Therefore, for every rational node in the system, it intends to choose an action that maximizes its utility function for a given action tuple of the other nodes, that is a best action $\bar{a_i} \in A_i$ is a *best response* for node i to $\mathbf{a_{-i}}$ iff for all other $a_i \in A_i$, $u_i(\mathbf{a_{-i}}; \bar{a_i}) \geq u_i(\mathbf{a_{-i}}; a_i)$
.

Definition A Nash equilibrium (NE) is an action tuple that corresponds to the mutual best response. Formally the action tuple $\bar{\mathbf{a}} = (\bar{a_1}, \bar{a_2}, \bar{a_3}, ..., \bar{a_n})$ is a NE if $u_i(\bar{\mathbf{a_{-i}}}; \bar{a_i}) \geq u_i(\bar{a}_{-i}; a_i)$. for $\forall a_i \in A_i$ and for$\forall i \in N$ [20].

Table 1. Prisoner’s Dilemma payoff matrix

	Node j		
		Cooperate	Incorporate
Node i	Cooperate	(p-c, p-c)	(-c, p)
	Incooperate	(p, -c)	$(0, 0)^*$

Therefore, a NE is an action tuple where no individual rational mobile can benefit from unilateral deviation. Since the interaction between two nodes in MANET is just the immediate neighbor nodes, a two nodes interaction game is modelled to represent the node’s interactions in the system.

3.3 MANET Without Stimulating Scheme

We assume that in the MANET, every mobile node generates some packets to a neighbor node who serves as a relay node. When two nodes are engaged in a interaction, they can choose a action in the action set (*cooperate (C), incorporate (I)*). A C action means it will help to node to forward the packet, while a I action indicate it will drop the packet. Accounting for all the facts during the transmission, such as interference, energetic cost and so on, we assume the cost for a node to forward a packet is $-c$ where $c > 0$, the benefit of a node’s packet is forwarded by other nodes is p where $p > c$. Then the payoff that two nodes will cooperate with each other is $(p - c)$. If one node incorporate to transmit packet and another node corporate to transmit the packet, then the defect one will earn a profit as p, while the cooperative one will get a profit as $-c$. If both nodes disagree to forward packets, the benefit is 0; Table 1 shows a payoff matrix of node i and node j.

From table 1 we can see that since $p > p - c$ and $-c < 0$, no matter what strategy node j adopts (the term strategy and action are interchangeable used in this paper), incorporation is the best strategy for node i if p>c, while no matter what strategy node i adopts, incorporation is also the best strategy for node j. Therefore, action set (I, I) is the unique Nash equilibrium is this interaction. However, it seems that it is not a very satisfying outcome, since (C, C) can give both nodes a higher payoff, this is (p-c, p-c) is much better than (0, 0). It is the famous Prisoner’s Dilemma payoff matrix [21].

Definition: An outcome of a game is non-pareto-optimal if there is another outcome which would give both players higher payoffs, or would give one player the same payoff but the other player a higher payoff. An outcome is Pareto optimal if there is no such other outcome [21].

Proposition 3.1 *How to stimulate the cooperation between the mobile nodes in the system is amount to how to change the Nash equilibrium to be Pareto Optimal on cooperation strategy.*

3.3.1 Game Theory Model for Reputation System

In the reputation system, most researchers proposed to adopt a reputation threshold value to distinguish the selfish nodes

Table 2. Payoff matrix for reputation system

	Node j		
		Cooperate	Incorporate
Node i	Cooperate	(p-c, p-c)	(C_i, I_j)
	Incooperate	(I_i, C_j)	(0, 0)

from the cooperative nodes. If the neighbor nodes are cooperative for the packet forwarding, the reputation values of these nodes are increased by the monitoring nodes. While if the neighbor nodes are detected to be incorporative, their reputation values will be reduced. When the reputation values of the selfish nodes are below a certain threshold, their routing requests will be refused by all other nodes. Regardless of their inherent problems in the system design, we mainly discuss the problems in the incentive strategies of these reputation based methods. If each node knows their current reputation value and wisely manipulate their packets transmission to keep their reputations just above the threshold, the system still can not reach their highest capacity because of the randomly drop of packet. It is assumed that the current reputation value of the node is R_c, and the threshold reputation value is R_t. In the first n interactions, a node choose k times incorporation, and $n-k$ times corporation. Supposes the average reputation credits gains for cooperation is C_c, and the average reputation lose for incorporation is C_i.

Lemma 3.1 *If a selfish node is managed to manipulate its reputation above a threshold value, the up bound of the packet dropping rate* p_d *is*

$$p_d \geq \frac{R_c - R_t + nC_c}{n(C_c + C_i)}$$

Proof Suppose in first n interaction, a selfish node adopt I strategy for k interactions before the reputation value the first falls below the threshold. Therefore

$$k \cdot C_i - (n-k) \cdot C_c \geq R_c - R_t$$

$$\Rightarrow \frac{k}{n} \geq \frac{R_c - R_t + nC_c}{n(C_c + C_i)}$$

Table 2 shows the payoff matrix for reputation system, where

$$(C_i, I_j) = \begin{cases} (-c, p) & \text{if } R_{I(j)} \cdot p_{d(j)} > R_t \\ (0,0) & \text{if } R_{I(j)} \cdot p_d(j) \leq R_t \end{cases} \tag{1}$$

$$(I_i, C_j) = \begin{cases} (p, -c) & \text{if } R_{I(i)} \cdot p_{d(i)} > R_t \\ (0,0) & \text{if } R_{I(i)} \cdot p_d(i) \leq R_t \end{cases} \tag{2}$$

Proposition 3.2 *Reputation game is Pareto Optimal.*

From table 2, we can find that if the reputation value of one of a pair of nodes below a threshold, namely R_t, the payoff value of these pair of nodes is (0,0). Therefore, the Nash equilibrium is at (C, C), and the game is Pareto Optimal. However, if a selfish node can manipulate its reputation value above the threshold value, that is, keep $R_c \cdot p_d > R_t$, the outcome of this game is still non-pareto-optimal with packets dropping rate as $\frac{R_c - R_t + C_c}{C_c + C_i}$

Table 3. Payoff matrix for price-based system

	Node j		
		Cooperate	Incorporate
Node i	Cooperate	(p-c, p-c)	(C_i, I_j)
	Incooperate	(I_i, C_j)	$(0, 0)$

3.3.2 Game Theory Model for Price-based System

In the price system, the researchers use virtual cash as an incentive to encourage the cooperation of the nodes in the system. All the interactions between neighbor nodes are done with the exchange of virtual currency. If the nodes do not have enough cashes for the transmission, all of its transmissions will be rejected. Therefore, we can build a new payoff-matrix for the price-based system. In addition to the original transmission cost c, packets benefit p, a new price benefit m should be introduced in the system. Table 3 shows the payoff matrix of a pair of interactive nodes. Between two nodes with transmission strategies (C, I), although an uncooperative node can still gain benefit from a transmission cost c, it should pay m for the transmission, while, although the cooperative node will suffer from packet losing p, it can earn a benefit m from forwarding. Table 3 shows the payoff matrix of price-based system ,where

$$(C_i, I_j) = \begin{cases} (-c+m, p-m) & \text{if} Cr_j > m \\ (0,0) & \text{if } Cr_j < m \end{cases} \tag{3}$$

$$(I_i, C_j) = \begin{cases} (p-m, -c+m) & \text{if } Cr_j > m \\ (0,0) & \text{if } Cr_j < m \end{cases} \tag{4}$$

Lemma 3.2 *Price-based game is Nash equilibrium with Pareto Optimal iff the transmission cost c, packet transmission benefit p, cooperation benefit m should satisfied* $p > c \&\& p > m$ *satisfy the relationship as*

Proof In order to have (C, C) strategy to be the Nash equilibrium with Pareto Optimal, according to the “minmaximizing” method [21], the pay-off values should satisfy

$$\begin{cases} p - c > p - m \\ p - c > 0 \end{cases} \tag{5}$$

therefore, $p > c \&\& m > c$.

Therefore, according to the lemma 3.2, proposition 3.3 can be got.

Proposition 3.3 *price-based game is Pareto Optimal if the price it earns is higher than its transmission cost and packet transmission benefit is also higher than its transmission cost.*

However, although the price-based system can stimulate the node's cooperation in the MANET, if a node accumulates a considerable virtual credits, it can still refuse to be cooperative until the credit is not enough. That is, the nodes can still manipulate their price to be a selfish node.

Lemma 3.3 *If a selfish node manages to manipulate its virtual credit value above zero, the lower bound of the packet dropping rate* p_d *is*

$$p_d \geq \frac{np_f + V_o - sp_g}{np_f}$$

Table 4. Payoff matrix for ARM system

	Node j		
Node i		Cooperate	Incorporate
	Cooperate	(C_i, C_j)	(C_i, I_j)
	Incooperate	(I_i, C_j)	(0, 0)

Proof Suppose in first n transmission requests, a selfish node adopt I strategy for k request. Meanwhile, it requests others to send packets for s times before the credit value below zero for the first time. The price for packets forwarding is P_f and the price for packets generating is p_g. V_o is used to denote the current credit value, therefore

$$(n-k) \cdot P_f + V_o - s \cdot P_g \leq 0$$

$$\Rightarrow \frac{k}{n} \geq \frac{np_f + V_o - sp_g}{np_f}$$

From the equation, it is obvious that a node with high initial virtual credits or small generated packets will result to a high packets dropping rate.

3.3.3 Game Theory Model for ARM System

In the ARM system, the incentive strategy combines the reputation system and priced based system. Reputation system is used to judge the cooperation degree of each node, based on which, the price is paid for the packets forwarding nodes. A node with higher reputation pay less price. A reputation threshold is also set for the reputation system. If a node's reputation value is below these thresholds, no matter how wealthy it is, it will be put into a "blacklist". That is, all other nodes will avoid any transmission request from it. Table 4 shows the payoff matrix for ARM system, where

$$(C_i, C_j) = (p - c + (\frac{m}{R_j} - \frac{m}{R_i}), p - c + (\frac{m}{R_i} - \frac{m}{R_j})) \tag{6}$$

$$(C_i, I_j) = \begin{cases} (-c + \frac{m}{R_j}, p - \frac{m}{R_j}) & \text{if } Cr_j > \frac{m}{R_j} \&\& R_{I(j)} \cdot p_{d(j)} > R_t \\ (0,0) & \text{if } Cr_j \leq \frac{m}{R_j} || R_{I(i)} \cdot p_{d(i)} \leq R_t \end{cases} \tag{7}$$

$$(I_i, C_j) = \begin{cases} (p - \frac{m}{R_i}, -c + \frac{m}{R_i}) & \text{if } Cr_i > \frac{m}{R_i} \&\& R_{I(i)} \cdot p_{d(i)} > R_t \\ (0,0) & \text{if } Cr_i \leq \frac{m}{R_i} || R_{I(i)} \cdot p_{d(i)} \leq R_t \end{cases} \tag{8}$$

Lemma 3.4 *ARM has a Nash equilibrium with Pareto Optimal if transmission cost c, current reputation value R_j and R_i, and cooperation benefit m satisfied $\frac{m}{R_j} > c \&\& \frac{m}{R_i} > c \&\& p > c$.*

Proof In order to have (C, C) strategy to be the Nash equilibrium with Pareto Optimal, according to the "minmaximizing" method [21], the pay-off values should satisfy

$$\begin{cases} p - c + \frac{m}{R_j} - \frac{m}{R_i} > p - \frac{m}{R_i} \\ p - c + \frac{m}{r_i} - \frac{m}{R_j} > p - \frac{m}{R_j} \\ -c + \frac{m}{R_i} > 0 \\ -c + \frac{m}{R_j} > 0 \end{cases} \tag{9}$$

therefore, $m > c \cdot R_j \&\& m > c \cdot R_i \&\& p > c$.

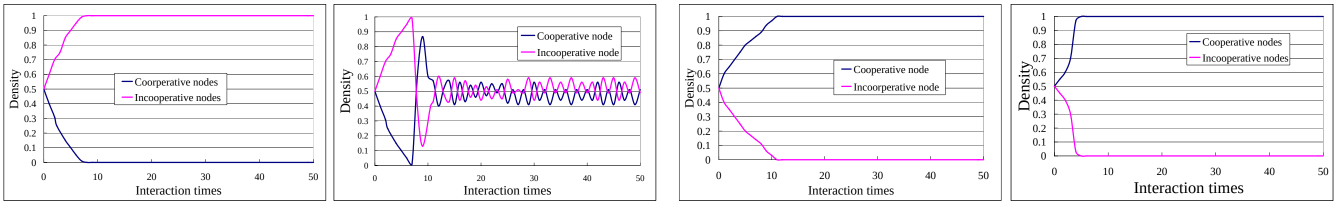
From the payoff matrix we can find that even a node has a considerable amount of virtual credits, if it refuses to cooperate with other nodes, although the virtual credits will not decrease, its reputation value will decrease. If the reputation value is lower than a threshold, the selfish node will be put in to the blacklist. Therefore, the selfish behavior of the nodes with high virtual credits and less packets generating need can be prevented. Meanwhile, a low reputation value lead to a high price for the packet forwarding, therefore, its virtual credits will be quickly used up. Therefore, it is impossible for a node to manipulate a reputation value just below the threshold value.

4 Performance Evaluation

Since in reality, the interactions between neighbor nodes are multiple-moves games, the nodes can change their interaction strategies as they want. Therefore, in this section, the performance of ARM, reputation system, price-based system are evaluated with a Monte Carlo simulation. In the simulation, 100 nodes identical distributed in the system randomly meet and play a multiple-moves game. Points based on the payoff matrix are then totalled for all players in each strategy. The number of players for each strategy in the next round of games (generation) is simply the relative success of the strategy multiplied by the total number of players in the population. It is assumed that the population size stays constant and just the proportion of players in each strategy changes. The new player numbers are rounded to the nearest integer. In the system, although the cost for each transmission is different, without loss of generality, we assume that the normalize payoff for the transmission is 2, packet transmission benefit is 4 to compare the performance of reputation system, price based system and ARM. We also suppose the initial reputation value of each node is 1.0, the reputation threshold is 0.3. A very simple calculation method is used to calculate the reputation values in the simulation, that is, every time when the nodes help to forward the packets, it increase by 0.1. Otherwise, it is reduced by 0.1. There are mixed of 50 cooperators and 50 defectors at the start.

Figure 1(a) shows the change of density of nodes in MANET with no cooperation incentive scheme. From the figure, we can find that after several interactions, the uncooperative nodes domain the population of the system. It is because in this scenario, the uncooperative strategy is the Nash equilibrium although it is not Pareto Optimal. Since the strategy of each node can change with each interaction, these self-interest nodes will no longer use cooperative strategy cause it can not bring it the safest and largest benefit.

Figure 1(b) shows the change of density of nodes in MANET with reputation system. The figure indicates that before about $8 - 9$ interactions, the uncooperative strategy is still the dominate strategy. It is because although the reputation of the uncooperative node decrease with the interaction times, the uncooperative strategy is still the Nash equilibrium before it fails below the threshold. However, when the reputa-



(a) MANET with no incentive scheme (b) MANET with Reputation system (c) MANET with price-based system (d) MANET with ARM system

Figure 1. **Comparison of cooperation system in MANET**

tion value of some of the nodes below a reputation threshold, their transmission requests will be ignored by other nodes, at this time cooperative strategy will be the Nash equilibrium. Therefore, the selfish node should increase their reputation by taking cooperation strategy. However, after the reputation value increase above the threshold value, the uncooperative strategy become the Nash equilibrium again.

Figure 1(c) shows the change of density of nodes in MANET with reputation system. The figure shows that the cooperative strategy is always being the Nash equilibrium.

Figure 1(d) shows the change of density of nodes in MANET with ARM. Since we give large payoff to the cooperative strategy and use node's reputation values to prevent the node with less transmission request from being the selfish node, the nodes converge much faster to the cooperation strategy in ARM than the normal price based system.

5 Conclusions

In this paper, a system integrating the traditional reputation system and price-based system are evaluated based on the game theory models. Such system can effectively prevent the selfish nodes in traditional reputation system from manipulate their reputation value, and stimulate the node with high number of virtual credits and few packet generating request to be cooperative with others. Simulation and analytical results show the high performance of the hybrid reputation system.

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