Credit-based Repeated Game Model Applied in Transfer Decision of Opportunistic Network

Cheng Zhang, Qing-sheng Zhu, Zi-yu Chen
Computer College, Chongqing University, Chongqing, China
Email: zc19999@sina.com

Abstract -**Because of the characteristic of network topology and application domain, the data transmission in opportunistic network depends on the 'Store-Transfer' operation between nodes in it. And there isn't the fix route or path in it. So the fitness transmitter-node choice is a key for the success of data transmission in network. But the decision-making for transmission is not an easy work. As a smart unit, the nodes do cheating operations for avoiding accept the data transmitter job. To reduce such cheating behavior of nodes, the idea of credit-cooperation and repeated games are involved. For a node, every game is considered as a part of repeated-game in its lifecycle. If it did a cheating-operation in a game, it would face the punishment with long time. And the profit gained from the cheating-operation would be counteracted mutually from the loss of punishment time. Moreover, usually the punishment is bigger than profits in fact. By such method, it minimizes the probability of cheating happened in the game theory and makes the game more efficient.**

Index Terms—**Game Theory; Transfer Decision making; Credit; Opportunistic Network**

I. INTRODUCTION

Opportunistic Network is a special self-organization network, which does not rely on the links between source node and target node. However, it takes advantage of the meeting-chance in the node movement path to accomplish communication. Such new data-transferred and route way is called 'Stored –Carried - Transferred'. By this characteristic route and transmission way, the Opportunistic Network provides a new model and application domain for mobile computation. In this model, the node needn't an integrity route table for transmission message. A node stores messages and carries them while it moves. And when it met a medium node, both of them are negotiating on whether transferring message or not. If the negotiation were accepted, the messages will be transferred from the sender to receiver. In the carried path of message, the best chance for transferred node is of key point for message transmission.

Due to the limitation of wireless communication, either mobile node can't reach all nodes in the Opportunistic Network. A message needs the co-operation among nodes in its transmission path to reach the target. But the co-operation behavior will consume limitation resource of nodes, such as power and memory. So not all nodes like to attend the co-operation and take part into the message transmission by no means. The refuse to co-operation behavior is called a selfish behavior of node. For such selfish behavior, the node just refuses to attend the co-operation with other nodes for transmission in order to maintain its own resource. But its selfish behavior may cause the message transmission to be failed. And the embodiment of selfishness is that the node cheats the opponent in the game by providing false information to make the result of game beneficial to itself.

The harmfulness of selfish in game can't be underestimated. The research mentioned in reference [1] shows the effect of network capacity and delay-time caused by selfish behavior in DSR router protocol. In the simulation result, we find that the selfishness of small part of nodes may cause the whole network performance fall down severely. So how to monitor and prevent the selfish behavior of nodes in network is a key question in research. And it directly affects the performance and result of message transmission in Opportunistic Network.

Considering the idea of credit co-operation and game theory, this paper introduces a repeated-game model based on credit co-operation. By setting up a repeated-game co-operation model, the idea improves the credit-degree in transmission decision combined with the punishment mechanism. And each node attending in the game has to compare the profit and cost in the game, which will lead it to improve honesty in the game.

The structure of the paper is as below: Some related researches are listed in part II. The repeated-game model with credit is introduced in part III. In section A of part III, the idea conversion from phase-game to repeated-game is mentioned, and the punishment mechanism to cheating node is discussed in section B of part III. Also the credit co-operation way is involved in section C of part III. An associated algorithm is designed in section D of part III. Then the simulation and results are showed in part IV and also the final conclusion is drawn at the last of the paper.

II. RELATED WORK

Reference [2] introduced a repeated-model among the IDS and selfish nods, which is used to check and avoid the selfish behavior in sensor network. And this model mainly focuses on encouraging co-operation among nodes by monitoring reputation mechanism. The IDS use the reputation value to evaluate the trust-degree of node

doi:10.4304/jsw.6.9.1649-1654

and send the result to the medium node. The reputation mechanism can help the nodes separate the selfish nodes gradually and to generate a group of trust sensor nodes. For such selfish nodes, they can improve their reputation value by attending the network co-operation. Also it proved the nodes can reach nash-equilibrium by co-operation. But in this model, it only considered the betray behavior of IDS unilaterally, and believed IDS was the main cause for nodes' cheating. However such idea ignored the selfish instinct of node and was lack of practicability.

Marti[3] introduced models named 'Watchdog' and 'Pathrater'. By intercepting the behavior of local nodes to evaluate the reliability of router, the model can avoid to select the router passing selfish nodes. Actually, this model awards the selfish behavior. To improve the performance of Watchdog, Mahajan discussed a modified protocol named 'Carch'[4] based on anonymous broadcast. Buchegger and Michiardi etc. designed the Confidant [5] and Core [6] reputation model based on Watchdog, and they tried to use message exchange to transmit the reputation of nodes to promote co-operation. But the disadvantage of these two models is that the mechanism is complicated and unreliable, and it easily to bring the problem of reputation in consistent [7].

Felegyhazi posed a game model based on the relationship among nodes' topology dependence [8]. And Srinivassan modified the model and designed GTFT model [9], which tried to use TFT strategy to balance the contribution of nodes. But both models only considered the effect of history profit, not mentioned the expectation of future profit from nodes.

Considering the shortages of such models mentioned above, this paper prompts a better model based on repeated-game theory with credit. By converting the phase game to repeated-game, the decision of two nodes can be seemed as a small part of the whole network and its life-cycle. So the history profit and future predicting-value are wholly taken into consideration in its' game choice. And if the node selects cheating, the future cost by punishment mechanism maybe counteracted or even taken up exceeding all profit it got. Both mechanisms combined will force the node to self-restriction in game, and improve the success ratio for message transmission.

III. Repeated Model with Credit

By observing the decision behavior of nodes in the Opportunistic Network and the whole path of message transmission, a scene can be found that every node may behave as cheating while attending the message transfer decision. Because storing and carrying message will consume resource of node, the node is unlikely to accept the role of carrier. And all behavior of its selfishness can be concluded as below:

1. The accepter magnifies its load to create an overload illusion.
2. The accepter selects negative strategy in game intentionally to cause the game equilibrium failed.
3. The sender modifies its' predict value to make the game equilibrium succeed and pass the message to accepter.

Because both sides in game are smart nodes, their cheating behavior will be harmful to the message transmission and the dynamic-stability in the network. And such three types behaviors will cause the game either failed (message can't be transferred) or successes easily (message transferred frequently). Both cause the negative effect to the performance of message transmission. So how to avoid or reduce the cheating behavior in game of message transfer decision is a key question for message transmission. The idea of repeated-game from game theory and credit from economy bring us a new direction to solve such question.

A. Phase Game and Repeated-Game

To simplify the analysis, some assumptions are made as below:

1. Each game follows the same rule and process.
2. All messages are the same size and the resource cost is the same to each transfer node.
3. There are N nodes in the network (N={1,…,n}). And the source nodes and target nodes for each game are divided into two sets named {Si,Di}, i=1,2,…,n.

Assuming node k is joined in a message transfer game, the profit is G and the cost is F, the probability of transferring is ak, the utility function of k is marked as Uk, and $U_k = \sum_{i=1}^{v_k} (a_k G) - F a_k b_k$ Here bk means the probability of node k receive the transfer request.

Because all nodes are reason individuals, they will adjust their transfer probability in the game cycle to maximize their utilities as $max_{0 \le a_k \le 1} U_k(a_k, a_{-k})$

Here $a_{-k} = (a_1, \ldots, a_{k-1}, a_{k+1}, \ldots, a_N)$ means all transfer probability of nodes except node k. From the analysis of nash-equilibrium, a conclusion is drawn that the profit of node depends on the message transmission probability of other nodes, which is irrelevant of its own behavior. But the cost of the node is only based on its transfer probability. So, for each node, in order to reduce the resource cost, they are willing to refuse accepting message and win more efficiency. But if all nodes in the network select such strategy, i.e. they refuse to accept message transfer request, the successful ratio of message transfer in the network will be zero and the message transfer process is stopped. From game theory, all of nodes reach a Nash-equilibrium status, but all profits of nodes are zero. So it's the worst case although it seems meeting Nash-equilibrium. And the reason to cause such case is that the nodes completely don't consider their present cheating behavior would bring in future. In fact, if the cheating behavior will bring punishment in the future, the node has to compare the profits with the cost from punishment. And if the punishment is more than profit gained from cheating, it will force the node maintain honest in operation, the utilities of node will also be increased.

In the life-cycle of node, the node seldom joins in only one game. And it may attend many games in different time with different opponents. And in the whole Opportunistic Network, a node may attend a game as a message carrier in one time, but in another time, it may attend another game as a message receiver. So, not only from the node life-cycle, but also from the whole network, the games for transfer decision are no longer a serious of different phase game, they are actually a multi-phase repeated-game process.

Assuming the repeated-game has been executed T times, and the node knows the opponents behavior in the past t-1 times. In reference of the way of describing utility function by discounting factor $\delta \in (0,1)$[10], the total utilities of node can be shown as: $\sum_{t=0}^{T} \delta^t U_k(\alpha(t))$ and $\alpha(t) = (\alpha_1, \ldots, \alpha_N)$.

Here $U_k(\alpha(t))$ presents the utility value of node k in t phase game. δ is a comprehensive value of co-operation patience of node k: the value of δ is more big, node k is more patient and care more about the benefit in long-term; on the other side, the value of δ is less small, node k care more about profit at present. The value of δ is always defined based on network and application scene. The value of dynamic-varying is smaller than stable network.

Although the power and memory capability are limited in a node, which means the life-cycle is limited, the games involving in the node are still seemed as an infinite repeated-game process. Because both opponents can't predict the end of the game, both of them can't do a cheating behavior in their last game. Also in game theory, if the end can't be predicted, the players have to evaluate the strategy and effect in the future by an endless repeated way.

Set T=∞ and the game is seemed as an endless repeated-game. The average utility value of k can be described as:

$$\underset{U_k}{\rightarrow} = (1-\delta) \sum_{t=0}^{T} \delta^t U_k(\alpha(t))$$

And the factor (1-δ) is used to measure the profit of phase-game and repeated-game with a unify ruler. One unit utility value of a phase is standard as 1.

Why does the repeated-game force the nodes abandon the cheating behavior and choose honesty? If a node made a cheating choice and was checked in the game, all nodes in the network would punish it in following games, and the cost in the punishment phase would exceed the profit got from the cheating behavior. So the honesty is the only reason choice for node.

B. Punishment Mechanism

To deter to the cheating node, a punishment mechanism mentioned in reference [11] is involved in the repeated-game. And its foundation idea is: in the repeated-game, if a node did cheating behavior and were checked, in the following games, all nodes in the network would isolate the node and refuse all transfer requests associated with the node. See as figure 1

If the punishment period is T times, the profit got in the t time with cheating operation will be offset by the

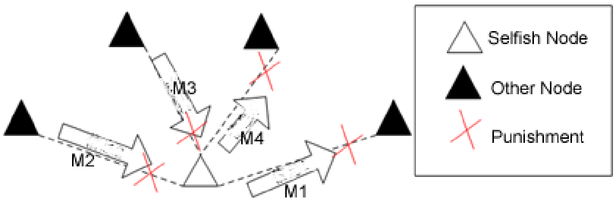

Figure 1 the punishment to cheating node.

lost in T period as punishment. If the node notices the difference between costs as punishment and benefit in long-term, there is no motivation for the node to do any cheating operations.

Define the Nash-equilibrium of phase game is $\vec{a} = (\alpha_1^*, \ldots, \alpha_N^*)$. And the corresponding utility function is

$(v_1^*, \ldots, v_N^*) = (U_1(\vec{a}^*), \ldots, U_N(\vec{a}^*))$

Then, Definition

$U = \{(v_1, \ldots, v_N)\} = \{(U_1(\vec{a}), \ldots, U_N(\vec{a}))\}$

$V = \{U\}$

$V^+ = \{(v_1, \ldots, v_N) \in V \mid v_k > v_k^*, \forall k\}$

And set V is the an available benefit set , V+ is the available benefit set meeting Pareto Optimized and Min-Max Profit.

Theorem I [2]: For $\forall (v_1, \ldots, v_N) \in V^+$, if existing $\underline{\delta} \in (0,1)$ and meeting the equilibrium for any $\delta \in (\underline{\delta}, 1)$, So called the node k has benefit v_k.

The theorem I shows the cost from the future operations will exceed the phase benefit from a cheating in a long-term. So in an un-endless repeated-game, if the attendance has enough patience, it will get reason benefit with Nash-equilibrium.

Set $\vec{a} = (\alpha_1^*, \ldots, \alpha_N^*)$ is union strategies for $(U_1(\vec{a}), \ldots, U_N(\vec{a}))$. And meets

$\forall \varepsilon > 0, \ (U_1(\vec{a}), \ldots, U_{k-1}(\vec{a}), U_k(\vec{a}) - \varepsilon, U_{k+1}(\vec{a}), \ldots, U_N(\vec{a})) \in V^+$

Set the maximum utility value of node k is $v_k = max_a U_k(a), \forall k$, which means the maximum utility of node k is got in the same time that all other nodes max the utility of node k. If the node is punished, the maximum utility value is $v_k - max_{a_k}[min_{a_k} U_k(a)]$. This value is corresponding to the phase Nash-equilibrium. If the node finish punishment period and return to co-operation state, the utility value is $v_k' = [U_k(a) - \varepsilon] \in V^+, \forall k$

Assumed that existing ε and the punishment period of k is Tk, and meets $\frac{v_k}{v_k'} < (1 + T_k)$

Then design the following steps:

Step I: if no cheating node is found in previous phase game, all nodes keep the co-operation state. If some cheating nodes are found, then turn to step II (node k is cheating as example).

Step II: By obeying to the punishment mechanism to punish the cheating node k. During the punishment period, all other nodes keep co-operation with each other.

Step III: Executing the strategy to make the utility value of cheating node k is $(U_1, \dots, U_{k-1}, U_k - \varepsilon, U_{k+1}, \dots, U_N)$. If the node is found have new cheating behavior in Step III, then return back to Step II and continue a new punishment period.

If node k return to co-operation state after punishment period, the profit with cheating is marked as vk, and the cost in punishment period is marked as vk, Then the profit in co-operation state is v_k' . So the average discounting utility value of node k is:

$$U_k = (1-\delta)v_k + (1-\delta)\sum_{t=1}^{T_k}\delta^t \underline{v}_k + (1-\delta)\sum_{t=T_k+1}^{\infty}\delta^t v_k'$$

If the node k always keep honest state, and its average discounting utility value is $U_k = (1-\delta)\sum_{t=0}^{\infty}\delta^t v_k$

So the profit of cheating of node k can be described as

$$\Delta U_k = \hat{U}_k - U_k = (1-\delta)\bar{v}_k + \delta(1-\delta^{T_k})\underline{v}_k + \delta^{T_{k+1}}v_k' - v_k =$$
$$(1-\delta)\bar{v}_k + \delta(1-\delta^{T_k})\underline{v}_k + \delta^{T_{k+1}}(U_k - \varepsilon) - U_k < (1-\delta)\bar{v}_k +$$
$$\delta(1-\delta^{T_k})\underline{v}_k - (1-\delta^{T_{k+1}})(U_k - \varepsilon)$$

Set $\underline{v}_k - 0, \forall k$, When $\delta \to 1$, $\frac{1-\delta^{T_{k+1}}}{1-\delta} \to 1 + T_k$. It can be drawn a conclusion that the profit of cheating is absolutely less than zero. It means the average co-operation profit is strictly bigger than cheating profit. So，it is impossible for rational nodes betray from the co-operation.

C. Credit Co-operation Mechanism

Definition I: the credit of mobile node is a degree value which measures the honest degree of node in the game.

Supposed that the total number of devices in Opportunistic Network is N. And the function of each node is the same. In order to simplify discussion, below are assumptions:

1. Assumption I: Each node only joins in one/none game in a time. And it can act as a message sender (sending message to another node) or receiver (accept the message from other nods).
2. Assumption II: The opponent in a game is random.
3. Assumption III: the opponent is considered as an honest one before the game started.
4. Assumption IV: the node doesn't know when it will quit from the Opportunistic Network, i.e. the node can't predict which game is the last game. So reverse derivation won't happen by any node.

Then we set definitions as below:

Definition II: The set space for credit value of node is Z={0,1}. 0 means honesty, 1 means cheating.

Definition III: During the game of nodes in Opportunistic Network, the strategies set of node is S={Co-operation, Non-cooperation},also marked as {Co,Uc} for short.

Definition IV: In a game, if the node obeys the formula below and select operation from it, called the node is honest in the game, otherwise called cheating.

$$\sigma(c) = \begin{cases} (Co_i, Co_j), if\ c_i = 0, c_j = 0 \\ (Uc_i, Co_j), if\ c_i = 0, c_j = 1 \\ (Cc_i, Uc), if\ c_i = 1, c_j = 0 \\ (Uc_i, Uc_j), if\ c_i = 1, c_j = 1 \end{cases}$$

Definition V: the rule for credit evaluation is: if a node were honesty in previous game (i.e. $c_i(t) = 0$), and did honestly in this game, set $c_i(t+1) = 0$. If it cheated in this game, then $c_i(t+1) = 1$. If a node cheated in previous game (i.e. $c_i(t) = 1$) and continued cheating in this game, set $c_i(t+1) = 1$. If it were honest in this game, then the credit value will be updated with formula3:

$$c_i(t+1) = \begin{cases} 1\ , \text{Assigning with probability } p \\ 0, \text{Assigning with probability } (1-p) \end{cases}$$

Parameter p means the punishment degree for the cheating behavior. If set p bigger, the node won't select cheating strategy for its own profit. If p=1, it is the 'trigger strategy'.

In the meantime, if in period of T+1, the credit value of a cheating node maintain $c_i(t) = 1$, then at the time of T+1, the cheating node return to honesty and the punishment is finished.

D. Algorithm Design

According to the analysis and conclusion in part C, the algorithm for the model is designed as below:

At initial phase, set all credit value of node in the network is zero. And set all counting device in node is n=0. The punishment period is T.

If all nodes obey the rules of **Definition I**V, all credit values of nodes keep zero. If one node's credit value varied from zero to one, this node falls into the punishment period and set n=T. In the following repeated-game, the node continues to join in, but only can act as a receiver. Only and if only the credit value for phase game is zero, set n=n-1; if the credit value for phase game is one, set n=T and continue a fresh counting. So if node k does a cheating operation in a game and falls into the punishment period, it must keep continual honest in the punishment period to end the punishment. The detail of algorithm sees as figure2.

IV. Simulation and Results

A. Brief introduction for the simulation

The simulation is based on Matlab 7. For the convenience of analysis and evaluation, the Opportunistic Network is consisted with 36 nodes, and all of them are placed in a region with 100m*100m random. Of course, the sub connected-domains have overlap. See as Figure 3.

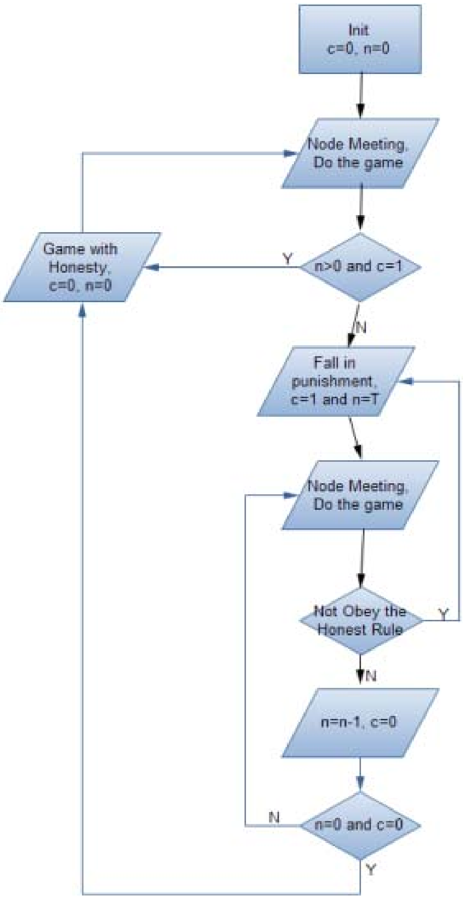

Figure 2 Algorithm for Repeated-Game with Credit.

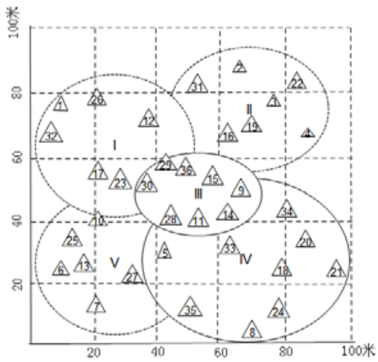

Figure 3 Node Place graph in simulation

B. the average utility of cheating node

Figure 4 shows the average utility of cheating node. If node 7 did cheating in the 10th game, the utility value of 10th game is much bigger than normal value. But in the repeated-game, its cheating behavior is found and falls into the punishment period, all nodes make punishment behavior to node 7 from 11th game. And the punishment period is 10. The data in figure 4 shows the profit of node 7 in punishment period is too less. And the average profit for a honest one is bigger than cheating one. So every node is likely to give up cheating behavior because it will cut down its benefit.

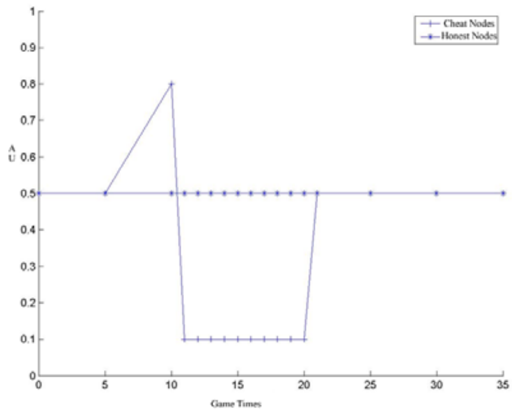

Figure 4 Average Utility of Utility

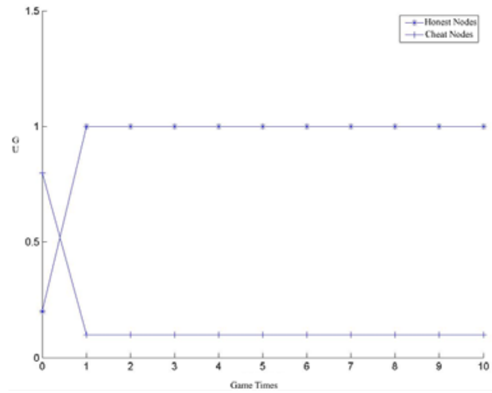

Figure 5 Comparison of global benefit for nodes

C. Comparison of global benefit between honest and cheat nodes

Figure 5 reflects the profit variation among honest node and cheating node. For the cheating node, the profit jumps to a high degree because of a cheating behavior and then fall down dramatically to the value of one because of long-term punishment.

D. Compared with non-cheat-deal game model

To validate the performance of cheat-monitor/deal, a comparison between this model (CR for short) and non-cheating-deal model (NR for short) is done, and more details as below.

In the simulation, a function named 'node cheating behavior' is involved. In the function, a decimal number is generated randomly and its range is [0,1]. If the random number is bigger than 0.5, the node behaves honestly in the game, otherwise it does cheating. The simulation imitates 10 route process of message from source node to target node with perhaps some cheating behavior in some medium node. And it records all nodes info during the message transmission, including the number of all passing nodes, the number of all transferred nodes, and all cheating function value of transfer nodes. The data in Table I is calculated by the records.

TABLE I. THE COMPARISON OF CR AND NR

	CR	NR
number for transfer/number for passing	74.3%	59.2%
ratio of cheating in transfer node	3.8%	22.3%
ratio of transmission success	82%	79%

In Table I, the ratio of ‘number for transfer/number for passing’ is presents the rate of nodes joined in the message transmission. Because of the selfishness of node, it may refuse to take part into the transmission so that the message needs more medium nodes to finish the transmission. And the message transmission maybe failed because of the selfishness..

The ‘ratio of cheating in transfer node’ is a Statistical value, which comes from the results of nodes’ selection of cheating or honest. For NR, the ratio value is less than 25%, and the CR is less.

V. CONCLUSION

In the Opportunistic Network, the message transmission has important role for applications. Because of the cost to the carriers, all nodes are not willing to take part into the transfer as a smart device. For carrier nodes, they prefer to transfer message to other nodes. And for free nodes, they are likely to run away when facing the transfer task. And such subjective idea always makes the node to do some cheating operations to avoid accepting the transfer task.

This paper focus on the scene happened in Opportunistic Network. From the global network and whole life-cycle of nodes, it converts the phase game of nodes into repeated-game and makes each game become one process of repeated-game. At the same time, it introduces the credit mechanism and punishment mechanism into the game. By punishment, it offset the profit from cheating of nodes. By credit, it’s helpful to identify the nodes are honest or cheating. By these measures, the nodes have to consider the cost brought along with cheating and then reduce the probability of cheating in games. The simulation result shows this model is helpful to improve the successful percentage of message transmission and reduce the probability of cheating.

ACKNOWLEDGEMENT

This research is supported by National Key Technology R&D Program of China (2007BAH08B04).

REFERENCE

[1] Pelusi L, Passarella A, Conti M. Opportunistic networking: data forwarding in disconnected mobile ad hoc networks[J]

[2] P. Michiardi, R. Molva. Simulation-based Analysis of Security Exposures in Mobile Ad Hoc Networks [C]. European Wireless Conference, 2002.

[3] Afrand Agah, Sajal K. Das.Preventing DoS Attacks in Wireless Sensor Networks: A Repeated Game Theory Approach [J]. International Journal of Network Security, 2007, 5(2):145-153.

[4] Marti S, Giuli T, Lai K. Mitigating routing misbehavior in mobile ad hoc networks[C]. In: Proc. of the ACM MobiCom 2000. New York: ACM Press, 2000. 255−265.

[5] Mahajan R, Rodrig M. Sustaining cooperation in multi-hop wireless networks[C]. In: Proc. of the USENIX NSDI 2005 Symp. on Networked Systems Design & Implementation. Berkeley: USENIX Association, 2005. 231−244.

[6] Buchegger S, Boudec Le JY. Performance analysis of the confidant protocol: cooperation of nodes fairness in dynamic ad-hoc networks[C]. In: Proc. of the ACM Int’l Symp. on Mobile Ad Hoc Networking and Computing (MobiHoc 2002). New York: ACM Press, 2002. 226−236.

[7] Michiardi P, Molva R. Core: A collaborative reputation mechanism to enforce node cooperation in mobile ad hoc networks[C]. In: Proc. of the IFIP-Communication and Multimedia Security Conf. 2002. 107−121. (in chinese)

[8] Hu JY. Cooperation in mobile ad hoc networks. Technical Report, CS-TR-050111, Florida State University,2005.http://www.cs.fsu.edu/research/reports/TR-050111.pdf

[9] Felegyhazi M, Hubaux JP, Buttyan L. Nash equilibria of packet forwarding strategies in wireless ad hoc networks[J]. IEEE Trans. On Mobile Computing, 2006,5(5):463−476.

[10] Srinivasan V, Nuggehalli P. Cooperation in wireless ad hoc networks[C]. In: Proc. of the IEEE INFOCOM 2003. Washington: IEEE Computer Society, 2003. 808−817.

[11] Borge Zhu, T.R.Er. The Game Theory [M].Beijing. China，2002:127-139.

[12] Eitan Altman, Arzad A. Kherani, Pietro Michiardiy, Refik Molvay. Non-Cooperative forwarding in ad-hoc networks [C]. Proc. of the IFIP Networking 2005. Heidelberg: Springer-Berlin, 2005: 486-498.