# Game Theoretic Model for Selfish Node Avoidance in Ad Hoc Networks

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**Abstract.** In this paper, a Game Theoretic Model for selfish node avoidance routing is presented. A mathematical framework for rational node that maximizes its credits has been developed. Using game theory, it is verified that that this proposed model is robust and can achieve full cooperation among nodes. The proposed model is simulated using network simulator ns-2 The simulation results show that game theoretic model improves packet delivery ratio with the increase in number of the routes in the network. It is shown that game theoretic model with AODV can achieve higher packet delivery ratio for heavy traffic network in the presence of selfish nodes as compared to the original AODV. Further, it is observed that the packet delivery ratio of cooperative nodes decreases proportionally when the number of selfish nodes increases. Furthermore, it is also shown that game theoretic model with AODV gives low routing overheads.

**Keywords:** Game Theory, Nash Equilibria, Cooperation, Selfish Node, Ad Hoc Network.

## 1 Introduction

Mobile Ad-hoc Networks are infrastructureless networks. These networks have no fixed routers, every node could be router. All nodes are capable of free movement and can be connected dynamically in arbitrary manner. The responsibilities for organizing and controlling the network are distributed among the terminals themselves. In this type of networks, some pairs of terminals may not be able to communicate directly with each other and have to relay on some terminals so that the messages are delivered to their destinations. These terminals as an evolution of current mobile phones, laptops, iPAD and emerging PDAs equipped with wireless interfaces. The only external resource needed for their successful operation is the bandwidth. The nodes may be located in or on airoplanes, ships, trucks, cars, perhaps even on people or very small devices [1].

In the absence of a fixed infrastructure, the basic network operations of wireless ad hoc network rely on cooperation of the nodes. The delivery of packets from source node to destination node relies on the several others nodes to help in forwarding the packets since destination is the beyond the transmission range of a source node. To increase the life time and energy efficiency of the network, it is allowing packets to be

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delivered over several short transmission links rather than one long transmission link. If the destination node is not directly approachable, the intermediate nodes between the source and destination make mutual contribution in the transmission by forwarding or relaying the packet along the route to the destination. However, the nodes in the ad hoc network may belong to different organization, company and person, so these nodes are autonomous and functioning for their own self-interest to minimize the use of their limited resources like energy, may refuse to forward packets for other nodes. This is the fundamental problem of the ad hoc network in which nodes are participating with selfish behavior. Selfishness of nodes may lead to inefficient use of the network resources since packets may have to be rerouted through alternative paths to the destination node or retransmitted when nodes dropped packets [2][3].

The researchers have addressed the several problems of inspiring the cooperation among nodes which promise to forward the packets but do not termed as misbehaving. They proposed many game theoretic solutions to enhance the efficiency of the networks with autonomous nodes acting on their self-interest to minimize the use of their limited resources. These solutions assumed to give nodes credit for packet forwarding or relaying for others node. The cooperative nodes earn credit through its behavior and use the accumulated credit to buying cooperative behavior from other nodes [4], [5] [6]. Another approach to inspiring the cooperation among nodes which agree to forward the packets based on the reputation of nodes gathered from neighboring nodes. These neighboring nodes continue to monitor the behavior of a node whether it is forwarding the packets or misbehaving with the packets [7], [8].

While the researcher provided many solutions to encourage the cooperation among nodes, still there are several possible drawbacks with these solutions. The monitoring nodes may be misinterpreting the behavior of nodes, increasing the computation to monitor the misbehaviors for other nodes, increasing the overhead on the network by consuming the channel capacity, forwarding the reputation information gathered from others nodes, and use its limited resources like energy for monitoring the misbehavior of others. In this paper, we proposed to use game theoretic approach to minimize the routing overheads and preventing the nodes becoming selfish in participating in routing.

## 2 Related Work

In the ad hoc networks, solutions for the problems of selfish nodes have been studied either using game theory or reputation systems. Recently there have been a sequence of research papers [2],[3],[4],[5],[6],[7], [9], and [10] published in the area of communication and ad hoc networks that made efforts to solve various problems introduced by selfish nodes. A node tries to select a strategy that maximizes its own gain called rational node. Some of these studies have a common approach of incurring the credits if they are considered to provide the service for others. While others have a common approach to motivate the cooperation among nodes by gathering secondhand information. Based on this information of neighboring nodes, a source node decides to forward packets through a node having good reputation.

Authors in [2] provided an introduction to neutral cooperation in the ad hoc network which is based on game theoretic analysis of selfishness of the nodes with a focus on the packet forwarding and relaying scenarios. Authors explained the two-player packet forwarding scenario and more-player packet forwarding scenario. In [3] a context-free (COFFEE) protocol is presented that does not rely on past experience and selfish behavior detection. This protocol can send packets through a route without knowing whether the intermediate nodes are selfish or not. In paper [4], Wireless nodes are considered with the energy constraints. Nodes are assumed to rational. A rational node means that its actions are strictly determined by self-interest. Each node is associated with a minimum lifetime constraint. The throughput of each node is measured in terms of the ratio of the number of successful rely requests generated by the node. The optimal tradeoff between the throughput and lifetime of nodes are studied using the game theory. A distributed Generous TFT (tit for tat) algorithms was introduce which decides whether to accept or reject a rely request.

In [5] a game theoretic model to investigate the conditions for cooperation in wireless ad hoc networks, without incentive mechanisms has been presented. Several theorems for the strategy always defects (AllD) are stated and proved for cooperation, considering the topology of the network and the existing communication routes. It is concluded that with a very high probability, there will be some nodes that have AllD as their best strategy. In [6] a reputation-based system as an extension to source routing protocols for detecting and punishing selfish nodes has been introduced. It is shown that by punishing these nodes will not benefit them. Instead, being cooperative has a better chance to increase their benefit. In [7], the local reputation information is used to decide the reputation value of nodes. Author suggested that every node have knowledge of the reputation value of all its neighbor nodes. Three reputation thresholds are given to categorize as good, misleading. The reputation of node is increased if it forwards a packet otherwise it is decreased. When the route is initiated, a node with good reputation is chosen. Otherwise, if no node is available with good reputation, it prefers to choose misleading node.

In [9] a game theoretic reputation mechanism is introduced to incentivize nodes which forward the packet for others, where cooperation is induced by the threat of partial or total network disconnection if a node acts selfishly. It is shown that a node which is perceived as selfish node due to the problem of packet collisions and interference can be avoided. In [10], an approach for detection of selfish behavior in the wireless mobile ad hoc networks is presented. This approach is based on Dempster-Shafer theory (DST) named as Dempster-Shafer theory based selfishness detection framework (DST-SDF). After reviewing the related work, it is observed that game theory can be used as the tools for analyzing selfishness and complex interactions between nodes in ad hoc network. Above techniques can be combined with other schemes, algorithms and analytical tools to derive a new framework for routing in wireless ad hoc networks.

## 3 Game Theoretic Model for Selfish Node Avoidance

In this section, a game theoretic model for analyzing the selfishness of nodes in forwarding packets is presented. Application of Game theory in this model is based on the hypothesis that a node forwards the packets rationally. In other words, each node has a utility function that a node tries to maximize with imposed constraints on its choices of actions in the game.

### 3.1 Preliminaries

It is assumed that an ad hoc network consists of two types of nodes - non-selfish node and selfish node but not malicious. These nodes are equipped with a limited power battery. A selfish node is a rational user that wants to save its energy by not forwarding the packet for others. The packet forwarding through multi-hop routes from the originating node to destination node relies on the intermediate nodes. Wireless links are bidirectional. The node listens to all the transmitted packets from their neighbors. The dynamic nature of ad hoc networks leads to imperfection or noise in transmission observed by a node.

A node consumes its resources in packets forwarding for others. It is assumed that the forwarding/relaying cost is $\beta$ where $\beta \geq 1$. A node receives a reward $\alpha$ when its packet is relayed where $\alpha \geq 1$. Any two neighbor nodes desired to send the packets to each other and also forward each other's packet. We can identify such pair of nodes and analyze interaction between them as a two-player game. It is reasonable to expect that the packet forwarding game between two players play several times since they decide whether to drop or forward their respective packets. It also assumed that time is divided into slots and a node is able to send sufficiently large number of packets in each slot. At the end of the each slot, the node monitors the throughput of its neighbor by overhearing. If throughput is below a certain threshold, it stops the transmitting packet. The node is denoted by a subscript $i$ and its neighbor by a subscript $-i$.

### 3.2 Forwarding Game Formulation

This section describes a two player packet forwarding scenario for natural cooperation. The natural cooperation between a pair of nodes is affected by different assumptions about the selfishness in packet forwarding and noise observed while overhearing.

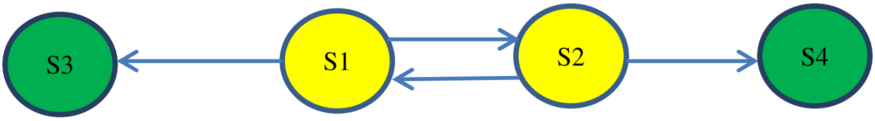

**Fig. 1.** A two player packet forwarding game scenario

This section describes a two player packet forwarding scenario for natural cooperation. In fig. 1, there are four nodes S1 to S4. S1 and S2 are willing to send packets to their destination S4 and S3 respectively. Without cooperation of S1, S2 is not able to send its packets to S3 and similarly, S1 can't send packets to S4. The set of actions are available to each player are as "forward" or "Do not forward" the packet of the other source. The payoff is defined as the difference between the reward of successfully delivered packets minus the cost of the forwarding a packet for the other sources. In this scenario, the payoff matrix of two player forwarding game is give in Table-1.

**Table 1.** Payoff Matrix of Two Player Forwarding Game

| | S2 DOES NOT FORWARD(DNF) | S2 FORWARD(F) |
|---|---|---|
| S1 DOES NOT FORWARD(DNF) | (0, 0) | (α, -β) |
| S1 FORWARD(F) | (-β, α) | (α-β, α-β) |

***Packet drop due to selfishness in packet forwarding***: - The packet forwarding through multi-hop routes from the originating node to destination node relies on the intermediate nodes. However, the intermediate nodes provide the packet forwarding, consume their limited energy resources. Therefore they, in order to conserve its limited energy resources could decide not to cooperate in the packet forwarding by switching off its interface. If many of them are acting selfishly by changing their behavior in this way, may lead to the collapse of the network. Nodes may choose to participate in packet forwarding but uses the minimum transmission power to deliver a packet acting as selfishly. Source node may not overhear this transmission, assumed that the packet is dropped by relay node. We define a drop probability $p_{-i}^{(t)}$ of node *–i* as

$$p_{-i}^{(t)} = \begin{cases} 0 \quad if \ \frac{E_c}{E_f} < \theta_{E,}, & Packet\ is\ dropped \\ \frac{E_c - \theta_{E,} E_f}{E_f - \theta_E E_f} \quad if \ \frac{E_c}{E_f} \geq \theta_{E,}, & packet\ is\ forwarded \end{cases} \tag{1}$$

where $E_c$ is the residual energy, $E_f$ is the full energy and $\theta_E$ is threshold energy ratio. The relay nodes monitor its energy level before forwarding a packet, if it is below $\theta_E$ then relay node drop the packet otherwise forward a packet. The $\theta_E$ may not be the same for all nodes.

***Packet perceived to drop due to noise observed in overhearing:-*** The nodes overhear all the transmitted packets from their neighbors. Due to noise in transmission, it is not always possible to detect whether a relay node forwarded a packet or not. A packet may be perceived to drop by *-i* since node $i$ is not completely overhear the packet transmission but it is not dropped. Let us assume that length of a packet is $L$ bits. If node $i$ did not overhear all $L$ bits of a packet, it is assumed to be dropped by *–i*. it is assumed that the loss probability of a bit is $p_b = 10^{-4}$. Probability that node $i$ overhear forwarded packet is $(1 - p_b)^L$. Probability that node *-i* drops a packet at time slot *t* is

$$p_e = 1 - (1 - p_b)^L. \tag{2}$$

A packet may be dropped either selfishness in packet forwarding or noise observed in overhearing. By overhearing the transmission, node $i$ then estimates the perceived dropping probability $\hat{p}_{-i}^{(t)}$ of its neighbor at time slot t≥0. Further, It is assuming that in each slot *t*, node *i* wishes to send *N* packets through node *–i* to its destination. The throughput of node *–i* estimated by node *i* in time slot *t* is can be expressed as

$$\tau_{-i}^{(t)} = N\hat{p}_{-i}^{(t)} .$$

$$= N\left[p_{-i}^{(t)} + \left(1 - p_{-i}^{(t)}\right)p_e\right] .$$

Substituting $p_e$ form (2) in above expression, we get

$$\tau_{-i}^{(t)} = N\ \left[\left(p_{-i}^{(t)} + \left(1 - p_{-i}^{(t)}\right)\right)(1 - (1 - p_b)^L)\right] \tag{3}$$

We defined the normalize throughput of node *–i* as

$$\hat{\tau}_{-i}^{(t)} = \frac{node\ i\ estimate\ number\ of\ packet\ forwared\ by - i}{actul\ number\ of\ packet\ send\ to - i}$$

$$\hat{\tau}_{-i}^{(t)} = \frac{\tau_{-i}^{(t)}}{N} = \left[\left(p_{-i}^{(t)} + \left(1 - p_{-i}^{(t)}\right)\right)(1 - (1 - p_b)^L)\right] . \tag{4}$$

The normalize throughput $\hat{\tau}_{-i}^{(t)}$ will be used as input to strategies function of node *i*. The average payoff of the node *i* at time slot *t* using the table -1 can be expressed as:

$$\pi_i^t = (\alpha - \beta)\left(1 - p_i^{(t)}\right)\left(1 - p_{-i}^{(t)}\right) + \ \alpha\left(1 - p_i^{(t)}\right)p_{-i}^{(t)} - \beta\left(1 - p_{-i}^{(t)}\right)p_i^{(t)} .$$

By simplifying:

$$\pi_i^t = (\alpha - \beta)\left[1 + \frac{\beta}{\alpha-\beta}p_i^{(t)} - \frac{\alpha}{\alpha-\beta}p_{-i}^{(t)}\right] . \tag{5}$$

A player wishes to maximize its total discount payoff and is given by [2]

$$U_i = \sum_{n=0}^{\infty} \delta^n \pi_i{}^t \ . \tag{6}$$

where $0 < \delta < 1$ is the discount factor. Substituting the $\pi_i^t$ from (5), the total discount payoff of node *i* can be expressed as

$$U_i = \sum_{n=0}^{\infty} \delta^n (\alpha - \beta)\left[1 + \frac{\beta}{\alpha-\beta}p_i^{(t)} - \frac{\alpha}{\alpha-\beta}p_{-i}^{(t)}\right] . \tag{7}$$

The payoff of node *i* can be calculated by using the actual value of $p_{-i}^{(t)}$from equation (1). If the node *i* supposed to have many chances for future interaction, then $\delta$ will be close to one.

### 3.3 Trigger Strategy

In the repeated game, each player is permitted to use a strategy to deicide its action "do not forward" or "forward" packets for others on the information collected in past. We define the trigger strategy in the two player repeated packet forwarding game to provide cooperation $\bar{\bar{P}}_i^t$ of a node *i* in time slot *t* such that the cooperation of a node -i is estimated based on normalized throughput $\hat{\tau}_{-i}^{(t)}$ in the time slot t-1. If the normalized throughput of a node is below a threshold $\tau_{th}$, it is consider a selfish node and node $i$ decided to not forward the packet of node –i. Mathematically the trigger strategy is defined as:

$$\bar{\bar{P}}_i^t = f_i\left(\hat{\tau}_{-i}^{(t-1)}\right). \tag{8}$$

where $f_i(.)$ is a strategy function of node i. There are many strategies possible. Few of them are given below:

$\bar{\bar{P}}_i^0 = f_i\left(\hat{\tau}_{-i}^{(0)}\right) = 0\,,$ Use this function if node-i playing DNF in the first time slot

$$f_i\left(\hat{\tau}_{-i}^{(t-1)}\right) = \begin{cases} 0 \quad \textit{if } \hat{\tau}_{-i}^{(t-1)} \leq \tau_{th}, & \textit{use this if Node} - \textit{i playing DNF} \\ 1 \quad \textit{if } \hat{\tau}_{-i}^{(t-1)} = 1\,, & \textit{use this funtion if Node} - \textit{i playing F} \\ \hat{\tau}_{-i}^{(t-1)} \ \textit{if } 1 < \hat{\tau}_{-i}^{(t-1)} < \tau_{th}, & \textit{use this TFT} \end{cases}$$

where DNF means “DO NOT FORWARD”, F means “FORWARD” and TFT (Tit-For-Tat). It is defined as a node i is playing this strategy start with F and then playing with the same throughput as of node-i in the previous time slot.

The strategy profile (DNF, DNF) is the only Nash equilibrium of the forwarding game with uncertain ending since neither player stands to improve their payoff from cooperation with an opponent that always do not forward. The dilemma of this game is that both players could receive a better payoff of $\alpha$-$\beta > 1$ if they selected the strategy profile (F, F). This strategy profiles is Pareto optimal.

# 4 Simulation

In the simulations, our focus is to study the performance of proposed game theoretic model for selfish node avoidance using the AODV protocol. The model developed is simulated in network simulator ns-2.

## 4.1 Simulation Setup

We used the two rays ground radio-propagation model for wireless channel. The bandwidth of the wireless channel is 2 Mbps. To propagate the signal in all direction, Omni directional antenna has been used. The multiple accesses with collision avoidance protocol (802.11) was used at the MAC layer. The physical radio range of node is 200 meters. Routing was performed using the AODV protocol with selfish node. The simulation parameters used in the work are shown in table-2. Initially, in the simulation, 10 nodes are randomly placed in an area of 500×500 $m^2$. We have implemented the proposed game theoretic model. During the simulation run we randomly selected 2 nodes that do not implement game theoretic model and behave selfishly by dropping all packets that are destined for others. A selfish node means a node that drop the packet to save its energy by not forwarding packet for others. A cooperative node is one which forwards the packets. Thereafter 20, 30, and up to 80 cooperative nodes are randomly selected and same number of selfish nodes are also selected for the simulation.

**Table 2.** Simulation parameter and its value

| PARAMETER | VALUE |
|---|---|
| Number of node | 100 |
| Number of selfish node | 10%-90% |
| Cooperative node | 10%-90% |
| Area | 500x500 $m^2$ |
| Packet size | 512 bytes |
| CBR | 5-30 packets/sec |
| Initial Energy $E_f$ | 1000 Joules |
| Threshold Energy ratio $\theta_E$ | .40 |
| Threshold Normalize throughput $\tau_{th}$ | .60 |
| Simulation time | 500 s |

To evaluate the performance of the network in which nodes implement two players game theoretic model, the number of forwarded packet are measured. We measured the following evaluation metrics - number of routes versus packet delivery ratio, CBR versus packet delivery ratio, and percentage of selfish nodes versus packet delivery ratio. Further, we also measured the metrics and percentage of selfish nodes versus routing overhead. *Packet Delivery Ratio* is defined as the ratio of the number of packet received at the destination node to the number of packets sent by the source node. *Routing Overhead is* defined as the ratio of the amount of routing related control packet in bytes (RREQ, RREP, RERR and Game Theoretic AODV) to the amount of data packet sent in byte in the network.

## 4.2 Simulation Results

Fig. 2 shows the simulation results obtained for Packet delivery ratio as the number of routes varies in the network where 10% nodes are selfish and 90% are cooperative

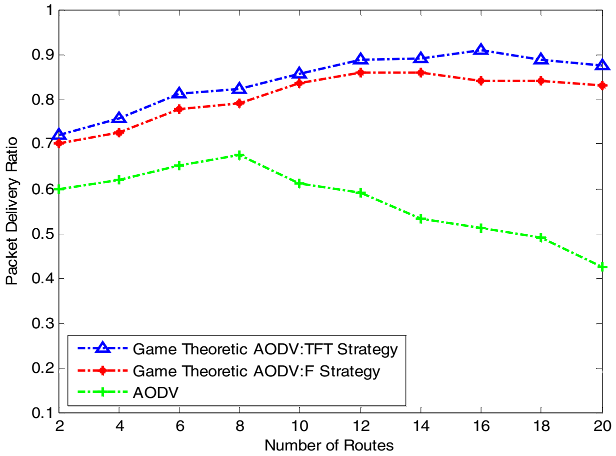

**Fig. 2.** Packet delivery ratio for the different numbers of routes

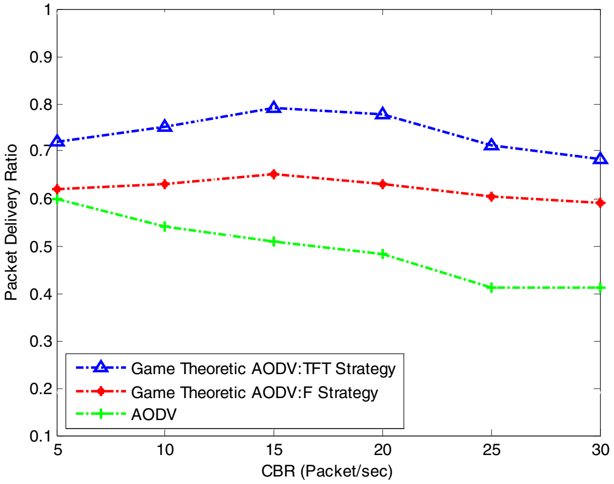

**Fig. 3.** Packet delivery ratio for the different packets rates

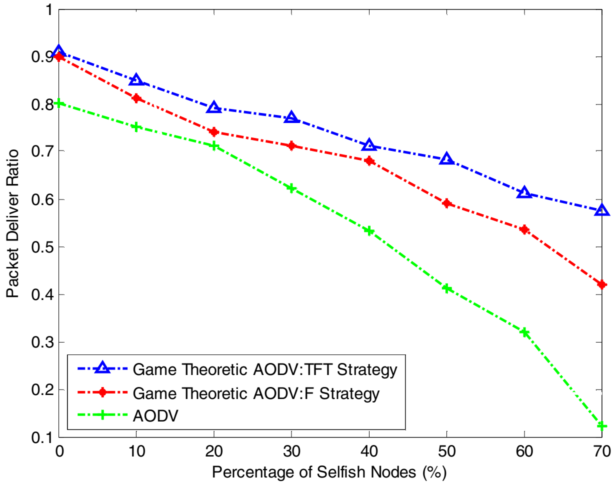

**Fig. 4.** Packet delivery ratio for the different number of selfish nodes

nodes. It is observed that the packet delivery ratio increases with the increase of the routes. This is due to fact that when there are more active routes, a node does not listen since it is busy in forwarding the increased number of packet. This is leading to consume more energy of node. Therefore cooperative nodes are supposed to be acting as selfish. This increases the level of retaliation situations in TFT strategies. When the number of route is more than 16, the packet delivery ratio starts decreasing since the packets are being forwarded by the originating node. But the packets are not overheard by the originating node due to bit error in packet overhearing which increases selfishness among the cooperative nodes. Further, packet delivery ratio of

AODV with selfish nodes falls drastically since nodes do not implement the game theoretic model for avoiding the selfishness.

Fig. 3 shows the simulation results for packet delivery ratios as the rate of CBR traffic of source nodes varies. It is observed that when CBR source generates more than 15 packets in one second, the packet delivery ratio start decreasing. . This is due to fact that when there are more cooperative nodes they might deviate from strategy F to strategy TFT to save their energy since forwarding of more packets consume more energy. Therefore cooperative nodes are supposed to be acting as selfish. Further, Packet delivery ratio for AODV decreases faster as the CBR increases compared to AODV with game theoretic model. It works efficiently in the heavy loaded network as compared to the original AODV in the presence of selfish nodes.

Fig. 4 shows the simulation results for packet delivery ratio as the percentage of selfish nodes and cooperative nodes varies in a network. The percentage of selfish nodes in the network is varied from 0 to 70%. The CBR for this simulation is 10 packets. It is observed that the packet delivery ratio for both strategy F and TFT is 0.90 and for AODV is 0.80 when none of the node is acting as a selfish node. Further, the packet delivery ratio of cooperative nodes decreases proportionally when the number of selfish nodes increases. This is happening because of two facts. First, as the number of selfish nodes increases, the total number of packets being dropped increases proportionally. Second, it decreases as the repeated route request is fired and the overheads for searching the alternative route are increased. Compared with the original AODV, the game theoretic modeled AODV protocol works better in situations where the selfishness among nodes is increasing. For example, there are 70% nodes are selfish, the game theoretic modeled AODV protocol delivers about 58% of the data traffic, while the original AODV protocol can only deliver 12%.

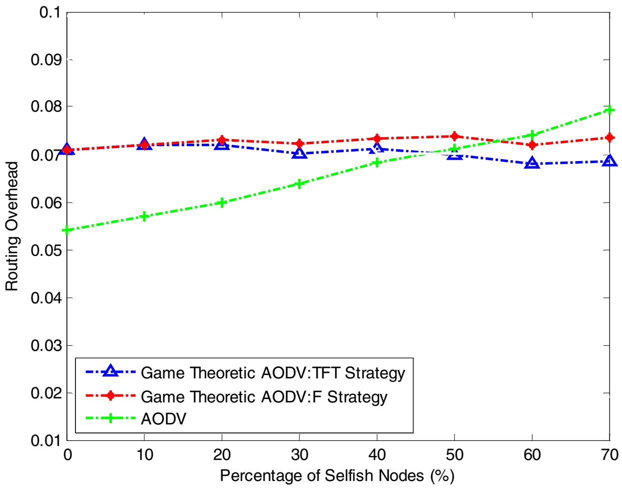

**Fig. 5.** Routing overhead for the different number of selfish nodes

Fig. 5 shows the simulation results for the routing overhead of the game theoretic modeled AODV for the different percentage of selfish nodes and cooperative nodes in the network. The percentage of selfish nodes in the network is varied from 0 to 70%. The CBR for this simulation is 10 packets. It is observed that the routing overhead increases to 7% approximately for the game theoretic modeled AODV while in the case of original ADOV it is 5.5% when no node is acting as selfish node. The routing overheads for the game theoretic modeled AODV increases very slowly with the increase of selfish nodes. While the routing overheads for the original AODV increases faster. This is due to fact that repeated route request are fired for route establishment and overheads are incurred in searching the alternative routes. For example when there are 70% selfish nodes, the overheads for the original AODV are 8.0%. While for the game theoretic modeled AODV protocol, it is only 7.5% since in the original AODV, the nodes do not implement the cooperation mechanisms.

## 5 Conclusion

We have studied how game theoretic model can help for selfish node avoidance routing by enforcing cooperation among selfish nodes. A mathematical framework for rational node that maximizes its credits has been presented. To enforce cooperation among the selfish nodes, two trigger strategies are used; game theoretic model with F (forward) and with TFT (Tit For Tat). Further, to explore the usability of this model simulations are carried out using NS-2. From the simulation results, the following observations are made: The gap between packet delivery ratio of the two cooperative nodes strategies increases with the increase in number of routes. This is happening since increase the level of retaliation situations in TFT strategies. The game theoretic modeled with AODV achieves higher packet delivery ratio for heavy traffic network in the presence of selfish nodes as compared to the original AODV. The packet delivery ratio of cooperative nodes decreases proportionally when the number of selfish nodes increases. This is happening because of two facts - first, the number of selfish nodes increases as the total number of packets being dropped increases, and second, firing of repeated route requests and overheads for searching the alternative route. The implementation of game theoretic modeled with AODV results in low routing overheads.

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