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Enhancing Cooperation Using Probabilistic Routing in Opportunistic Mobile Ad Hoc Networks

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Abstract: Opportunistic network is an advanced technique for communication in mobile ad hoc networks in which end to end paths are unstable. To enable this end to end communication in opportunistic networks, several routing protocols have been proposed in the past and it is purely based on probabilistic routing. However, when nodes are behaving selfish manner, probabilistic routing does not have any mechanism to make them to participate. Hence, this research study proposes to make the selfish nodes to participate and cooperate for reliable communication in MANETs. The incentives are awarded to selfish nodes for their participation and cooperating to forward the packets in this opportunistic network which leads to gain in delivery ratio and increased system performance with reduced communication overhead.

Key words: Bargaining, incentives, MANETs, opportunistic network, routing, selfish nodes

INTRODUCTION

With the increase in usage of mobile wireless devices, the concept of opportunistic network has also increased importance in Mobile Ad hoc Networks (MANETs), Mobile Social Network applications and Delay-Tolerant Networks (DTNs). Opportunistic networking is an advanced technique for cooperative communication in MANETs to make the selfish nodes to participate in communication as cooperative if end paths are unstable. In such mobile ad hoc networks, due to the links of transitivity type, the message transmission that starts from at least one user to another user based on store and forward fashion. The opportunities for forwarding arise when mobile devices come within their communication range of each other. When compared with traditional networking techniques, messages are delivered on the pre-existing end to end paths, rather than the messages are transferred from the source to any destination, even if there is no specified path from the source to destination. Recently, many routing protocols have been proposed in the past to support messaging service from source to destination in opportunistic networks (Lindgren *et al*., 2003; Huang *et al*., 2008). Among them, the probabilistic routing protocols are used in the large part of message transmission in opportunistic mobile ad hoc networks.

This routing protocol carries message with the neighboring nodes that estimate the probability of the other node to forward the message to next nodes. This probability is to decide when the messages are forwarded to one node to another node and it calculates the node capability of message transfer for cooperation. The probabilistic routing is more practical and effective technique in the world of research in opportunistic networks. The probabilistic routing may ensure a better role in cooperative communication when all nodes are behave trustworthy to adopt this type of routing protocol that it leads to reduce the network performance when nodes behave selfish manner. These types of opportunistic networks are similar to many distributed autonomous systems that suffer from common incentive problems when nodes are in selfish state. Theses selfish nodes do not behave cooperatively during message transmission if they are not rewarded considerably and as they do not have incentives to behave cooperatively. If the selfish node wish to deliver their own messages through other nodes but refuse to deliver other node's messages if they are not properly compensated. Then, the performance of the network will degrade significantly. In wireless networks, most of existing incentive schemes are purely based on the contemporaneous end to end connections and they do not apply for probabilistic routing schemes.

This research work is proposed to validate the selfish nodes and to start bargaining. Also this approach is purely motivated based on the observations and the messages that are exchanged using probabilistic routing. The node with higher delivery probability could earn some profit by forwarding packet from a lower delivery

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probability node. Thus, an opportunity is created for selfish node to earn incentives and participate in the packet transmission. In this research, the idea behind bargaining theory (Muthoo, 1999) is used to solve problems of incentives in probabilistic routing. According to Bargain Theory, the negotiation process is initiated for creating an agreement between two parties so as to exchange or sell and also based on the mutual agreement. The design of message exchange process for a pair of nodes in this routing process is done using a bargaining game. Then, message is transferred from a given source to the corresponding destinations, then the series of bargaining game is initiated. When this series of bargaining games gets completed, the messages are successfully sent to its desired destinations. On carefully analyzing the part of involvement in bargaining game, the incentive scheme is mainly used to stimulate the cooperative behaviour in probabilistic routing. The contributions of proposed work are as follows:

- Validation of selfish nodes before starting the bargaining games
- Modeling the process of probabilistic routing which is similar to a series of bargaining game

LITERATURE REVIEW

This study carefully reviews the literature survey related to selfish node in MANETs, opportunistic routing and cooperative incentive schemes. Also the considerable amount of work insists the cooperation problems and trust based problems in wireless networks. Wang *et al.* (2006) designed Nash equilibrium mechanism which explicitly differs from traditional strategy. Li and Shen (2012) proposed the analysis of cooperative incentive scheme for systems with and without cooperation incentive strategy.

In cooperative packet forwarding there are two different approaches named route selection approach and packet forwarding approach. Anderegg and Eidenbenz (2003) have proposed the route selection approachand the calculation of lowest cost path despite of the fact that selfish nodes can make false claims about their costs. Mostly it works only if there are end to end routes. Similar to the packet forwarding approaches. Chen and Chan (2010) and Chen and Zhong (2010) addressed credit based incentive system to stimulate the selfish nodes in delay tolerant and wireless network was carried out in detail. The routing misbehaviour was presented by Marti *et al.* (2000). Srinivasan *et al.* (2005) proposed a cooperative mechanismin wireless networks. Srikant and Jaramillo presented the tit-far-tat strategy through listening relay nodes and punishing the misbehaving nodes. They proposed tit-for-tat like incentive mechanism to reward or punish their neighbouring nodes with the historical data. Moreover, Shevade *et al.* (2008) was developed an incentive-aware routing protocol and it allows selfish nodes to maximize their own performance by t-f-t constraints. From the above works, they clearly aim the cooperation and reputation through various schemes.

In some games virtual money or credit is used to compensate for participants in game and for packet forwarding. Buttyan and Hubaux (2000) were the first one who proposed the virtual money as incentives in the packet forwarding approach. The above proposed solution needs a tamper proof hardware for each node. Zhong *et al.* (2005) proposed another credit based solution without any tamper proof hardware. Moreover, Jakobsson *et al.* (2003) used a payment scheme which worked at a micro level. Chen and Murphy (2001) and Wu *et al.* (2008) carefully analysed the incentive issues that rose due to packet forwarding and coding-based opportunistic routing in mobile ad hoc network.

On an observation, many of researchers used the incentive schemes based on credit for successful stimulation of mobile nodes in the delay tolerant network for helping other nodes in packet forwarding. Mahmoud and Shen (2010) presented a combined scheme for reputation and credit to stimulate cooperation between mobile nodes.

TECHNICAL PRELIMINARIES

In this proposed research, the probabilistic routing protocols, proposed methodologies and game theoretical solutions are discussed as follows:

Routing protocol for probabilistic routing: The objective of this proposed research is to create a incentive scheme for several classes of probabilistic routing protocols. Specifically, the model is designed based on the routing protocol and the concentration to formulate the proposed scheme on this protocol is purely based on probabilistic routing protocol so as to make it incentive compatible. In general the nodes do not like to move around in a random motion but prefer to move in a predictable way which is based on the mobility patterns. When a pair of nodes has met several times earlier, it is similar that they will meet again in the future. The exploitation of mobility patterns delivery probability is introduced for improving the routing protocol performance. Assume that $P_{a,b}\in(0, 1)$ be the delivery probability from node a to b where b node is a destination node. The success of delivering message to desired destination is achieved through these matrices and it is used to store the delivery probabilities. Therefore, the nodes exchange their own delivery probability matrices when they meet each other. The internal delivery matrix is updated for probabilistic routing. Through this matrix, decision is taken so as to decide which message to select for forwarding packet from one node to another node. Formally, a basic probabilistic routing protocol works as follows:

Algorithm for forwarding messages: Assume that node a meets node b and they would like to exchange messages. Initially node a sends node b the list of messages that node a is planning to carry with their corresponding destinations. Every message is also annotated by a with a's delivery probability. Node a receives the list of messages from node b and on successful recipient of messages it calculates the delivery probability of node b's messages. Node a requests from node b to send the list of messages which has higher delivery probability than the other node b by a minimum θ.

Probabilistic calculation for delivery: There are two part of calculations. The initial part is to calculate the probability of each node when they meet each other. Assume that $\rho_{a,b}$ is the estimated probability for a node to meet each other. The computation of $\rho_{a,b}$ is based on the recorded events of the nodes which are in motion during the last τ time slot where time slot is defined as a time which is fixed in its length (say a single day or single hour which purely depends on the speed of mobile node). Then, the initial probabilistic routing protocol function f1 () is calculated as:

$$\rho_{a,b} = f1(\{e^{t-t'}_{a,b} \mid t' \in \{1, 2, ..., \tau\})$$

Where:

- t = Defined as the time slot which is based on current time
- $e^{t-t'}_{a,b}$ = Calculates whether the node a and b can they meet in time slot t-t'

The transitive property of previous computed meeting probability is also considered to forth coming calculations of delivery probability $P_{a,b}$. The basic probabilistic routing protocol also specifies a function f2() which computes:

$$P_{a,b} = f2(\{(a, b, \rho_{a,b}) \mid a, b \in V\})$$

here, V denotes the set of nodes in this system. The different instances of the probabilistic routing protocol are achieved using different function f1 () and f2(). MV and the PROPHET are both instances of examples probabilistic routing protocol. Protocols that are defined and also the instances of this specific class are enhancing the scaled estimation to a range [0, 1]. The existing probabilistic routing protocols lack of incentive mechanism and the selfish nodes do not forward messages from one to another node for free. In some applications, an efficient incentive mechanism is required to stimulate the selfish nodes to forward messages in MANET's. Then, only the messages are sent to the node with a higher delivery probability and there by reaching the destination finally.

Solution using bargaining game: The message forwarding process similar to a bargaining game is proposed in this research. Specifically, the set of nodes are isolated when they come into the communication range the interaction among the nodes for possible message transfer via a bargaining game is designed. Either one of these two nodes are the current carrier of the given message and based on this the forwarding message to the specified node is determined. In bargaining game process that there are two players, one who sells the message in this case it is seller S and another one who buys the message is buyer B. In this model, the function N is equivalent to {S, B}. These players need to agree for the given price at which the seller S sells the message to buyer B.

The bargaining game is played in different form of rounds. For each round, the S makes a proposal to B and the buyer B takes a decision whether to accept or not. When the buyer B accepts the game ends automatically and the vice versa proceed to the next round. A strategy si is created for player $i \in N$, where N is the function which helps in assigning a action to player I when its turn is to move. Here, the -i represents the player apart from the player i who is involved in the bargaining game. A similar way of representing s-i defines the strategy of the player apart from the player i. Here, s = (si, s-i) is a strategy profile. On reaching this agreement with the purchase price x and in round r, the utilities of the players are:

$$u_S = x - V_S(m) - T(m) - C_S(r) \quad (1)$$

$$u_B = V_B(m) - P(m) - x - C_B(r) \quad (2)$$

Where, $V_i(m)$ is the valuation of message m to player i, T(m) and P(m) is the costs associated with the transmission and reception of message m, $C_S(r)$ and $C_B(r)$ is the bargaining costs of seller S and buyer B in the procedure of the game.

Based on the specifications $V_i(m)$ is the integrated message valuation of node i and its down stream nodes. In a bargaining game, if -i is i's down stream node, then $V_i(m)$-$V_i(m)$-T (m)-P(m) is this game's profit margin. The $V_i(m)$ is determined as follows. Then as per the assumption of this scheme, the node whoever deliver the message m to destination node can get a payment ω from the source node. The bargaining cost is not deducted here based on the design of the bargaining scheme because that it is assumed as a variable. Considering the previously defined delivery probability $P_{i,\ d}$ where, d denotes the destination node, the valuation of a message m at node i is as follows:

$$V_i(m) = \omega \cdot P_{i,\ d}$$

From the above, a node which has only higher delivery probability can also possess a higher valuation. For every node, it has to possess incentives for purchasing the message from the nodes with lower delivery probability. Further, the message is forwarded to the node with higher delivery probability and finally it reaches the destination. Also the trustworthy and its utilities are not considered in this research. These type of trustworthy validation based on the nodes reputation is planning to considered in the other future research assume that each of the two player nodes S and B incurs a cost σ>0 for every round of the game. Then, we have $C_S(r) = C_B(r) = r \cdot \sigma$.

To enable nodes to pay each other, virtual currency and credit clearance center is assumed in the system. The node has an account in the CCC and each transaction has to be processed by the CCC System. Each node keeps a digitally signed receipt for each transaction and submits receipts to the CCC and is connected to the internet. So, the node can access the CCC whenever they have connections with an internet. The CCC clears the transaction after receiving the receipts. Let R be the maximum number of rounds for bargaining. If the players do not reach any agreement after R rounds of bargaining, then their utilities are:

$$u_S = -C_S(R) \quad (3)$$

$$u_B = -C_B(R) \quad (4)$$

The value of R is known by all nodes and the players always keep bargaining for the possible message exchange, until an agreement is reached or the bargaining reaches the last round.

INCENTIVE ANALYSIS AND DESIGN SCHEME

The importance of incentive scheme is clearly described in this research. If there is no proper incentive scheme, the selfish nodes are not interested to communicate with the other nodes in mobile environment. Then, a trading scheme is proposed for message forwarding which leads a unique sub-game perfect equilibrium. In this sub-game perfect equilibrium, an agreement between the two players is reached immediately in first round, so that the message can be forwarded from the seller to the buyer without any hassle. Table 1 illustrate various important variables used in this scheme.

Analysis of proposed system without scheme: The standard analysis method is extracted from bargaining theory which represents the buyer cannot get any benefit from the trading, without the proper incentive scheme, i.e., In each round r, the seller S makes a proposal x and the buyer decides whether to accept it or not and the bargaining process lasts until an agreement is reached or the bargaining reaches the last round R. Then, through this analysis the bargaining process backwards and starting from the last round that the best strategy for the seller S is concluded and proposed as:

$$x(r) = V_B(m)\text{-}P(m) + (R\text{-}r) \cdot \sigma, \text{ in round r}$$

From the above analysis, the buyer B always gets negative utility and no matter that an agreement is reached or not if there is no proper incentives. This result inevitably hurts the buyer's incentive to buy the message. Hence, the selfish nodes refused to participate in the game. Then, the necessity for creating a message trading scheme is to help the mobile nodes to participate in the bargaining game.

Message trading scheme: The messages can be successfully forwarded based on the mobile nodes' participation using this message trading scheme. The main idea of the message trading scheme is to influence the players' strategy by introducing a carefully designed transaction fee which is referred as X(m, x) where the transaction fee of the message m at price x. Also the transaction fee is included in the final purchase price and

Table 1: Variables used in this scheme

Variables	Description
N = {S, B}	Set of players where S is the seller and B is the buyer
$V_i(m)$	Valuation of message m to player i∈N
T(m)	Transmission cost of message m
P(m)	Reception cost of message m
R	Round of bargaining
$C_i(r)$	Bargaining cost of player i∈N in r rounds, $C_i(r) = r \cdot \sigma$
U_i	Utility of player i∈N
R	Maximum number of rounds for bargaining
Γ	Small primary transaction fee
x, x_	Message trading prices
X(m, x)	Transaction fee

the seller gives out some of her profit as transaction fee when accessing the CCC to clear the transaction. The advantage of introducing the transaction fee is that by choosing a formula X(m, x). The seller's best strategy is influenced in the game, such that her offer in the first round is a reasonable price for the message. This price is reasonable that it makes the transaction profitable for both parties, i.e., both parties can have the positive utilities in the game. Further, accepting this reasonable price is also to the best interest of the buyer. The X(m, x) is represented as:

$$X(m, x) = \frac{\{\gamma \text{ if } x \leq V_S(m) + V_B(m) + T(m)\text{-}P(m)\}}{2}$$

Message trading scheme: The message trading scheme does the following:

- First the nodes exchange the lists of messages they are planning to carry. If one of the node (buyer B) wants to buy a message m from another node (seller S)
- Therefore, each round r≤R, starts from r = 1, now the seller node S will make a proposal x which is the purchase price and now it is up-to the buyer B to either accept or reject. If it is accepted by the game and it ends upon reject the round that it is increased r+1
- If suppose an agreement is successfully reached, the seller node S transmits the message m to the buyer node B and buyer node B will pay the price x to the seller node S. If there are no proposals ever accepted then the result will be a disagreement
- If the seller node S has a connection to the CCC (Credit Clearance Center) that it will clear the transaction and will pay a transaction fee X (for the message m, price x):

$$k(x\text{-}V_S(m) + V_B(m) + T(m)\text{-}P(m)/2) + \gamma \text{ o.w.}$$

where, $\gamma \leq (V_B(m)\text{-}V_S(m)\text{-}T(m)\text{-}P(m))/2\text{-}\sigma$ is a very small primary transaction fee and $k = 2\text{-}2\gamma/(V_B(m)\text{-}V_S(m)\text{-}T(m)\text{-}P(m))$.

Analysis of proposed scheme: For notational clearance, we let u^r_i denote player i's utility when it reaches an agreement in round r. Suppose an agreement is reached in round r. The utilities of the seller S and the buyer B become:

$$u^r_S = x\text{-}X(m, x)\text{-}V_S(m)\text{-}T(m)\text{-}r \cdot \sigma \quad (5)$$

$$u^r_B = V_B(m)\text{-}P(m)\text{-}x\text{-}\sigma \cdot r \quad (6)$$

If the disagreement event is reached, then the utilities of the players are:

$$u^D_S = u^D_B = \text{-}R \cdot \sigma \quad (7)$$

EVALUATIONS

We integrate the designed schemes with MV routing (Buttyan and Hubaux, 2000) and evaluation of proposed system is simulated using NS2. The evaluations are two parts, i.e., one is to verify the designed schemes and used to prevent nodes from being selfish. The other is to measure the influence of designed schemes on delivery ratio of probabilistic routing in a mobile ad hoc network with selfish nodes.

Methodology: The 10, 20, 30 and 40 mobile nodes in mobile ad hoc network are randomly distributed in a terrain area. Each node has three locations in the physical terrain and randomly travels among these locations with a uniform speed. We used two way Ground Propagation Model and link layer type layer. The antenna type is Omni Antenna Model and the transmission range is 250 m. We used the traffic type as CBR and the AODV is used for packet forwarding. In the model, we set p = 0.01 and q(r) = 0.1+0.01 (r-1) where r≥1.4 here q(r) is not limited to linear function. It can also be quadratic function, reciprocal function, exponential function, etc. However, the evaluation results of using different functions for q(r) are identical. Therefore, the result for linear q(r) is presented in this simulation.

Node behavior: In the evaluations, we compare two types of node behavior:

- Cooperative behavior: following the scheme faithfully
- Selfish behavior: the selfish nodes are not interested to participate in message forwarding among them. The results are presented when 30 and 70% of nodes are selfish

Metrics: The three metrics are evaluated as follows:

Packet delivery ratio: It defines the ratio between number of delivered messages and total generated messages. Delivery ratio reflects the impacts of proposed designed schemes based performance analysis in an opportunistic network with selfish nodes. Figure 1 represents the performance analysis in an opportunistic network without selfish nodes and 30% selfish nodes.

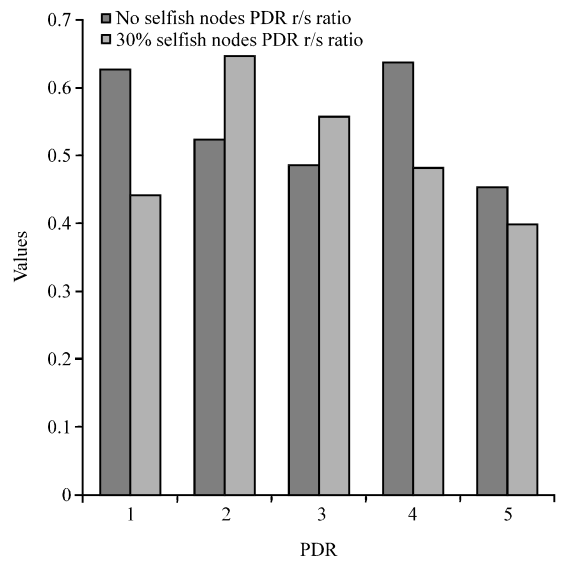

Fig. 1: PDR between without selfish nodes and 30% of selfish nodes

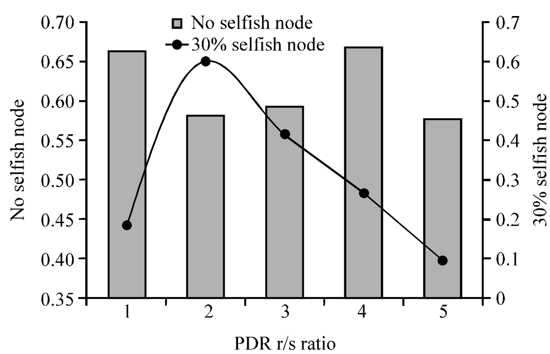

Fig. 2: PDR ratio among opportunistic network with few selfish nodes

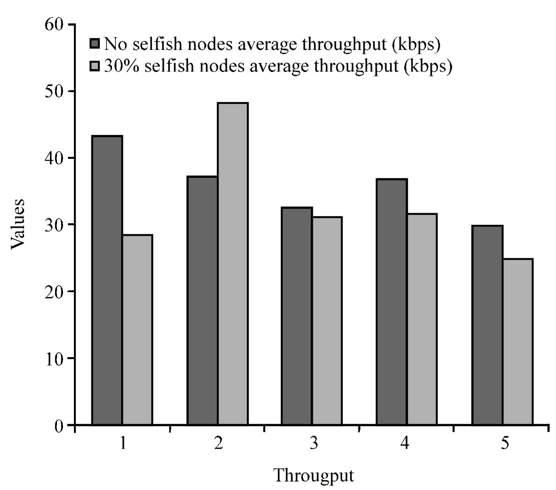

Fig. 3: Throughput analysis between no selfish and 30% of selfish nodes

Throughput: The throughput is increased only when better connectivity is provided. It can be observed that the performance of our proposed designed scheme is pretty much better even with 30% of selfish nodes and the throughput is measured in kbps. Figure 2 and 3 represent the performance analysis without selfish nodes with 30% selfish nodes.

End to end delay: End to end delay which represents the average time and it takes a data packet to reach the desired destination. This includes all possible delays that occurred due to buffering during the route discovery latency module which further queued at the interface. The calculation is made timely and hat which the first packet was transmitted from the source at the given time at which the first data packet successfully arrived to destination. Mathematically, it can be defined as (Fig. 4-6):

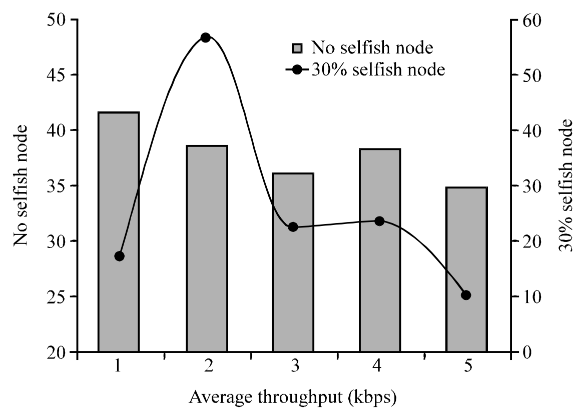

Fig. 4: Throughput with selfish nodes and without selfish nodes

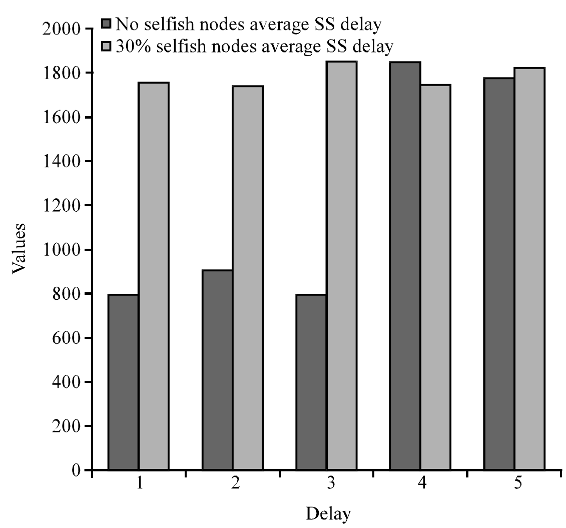

Fig. 5: End to end delay analysis through few selfish nodes and without selfish nodes

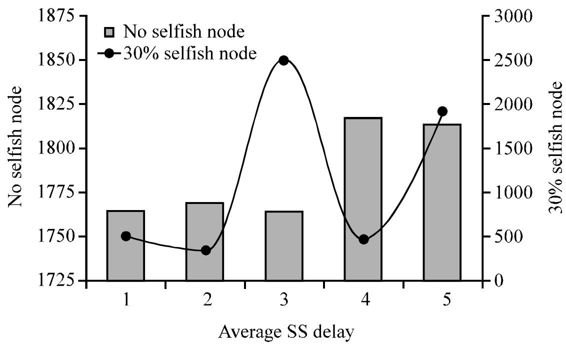

Fig. 6: Analysis for average end to end delay

$$\text{Avg. EED} = \frac{S}{N}$$

Where:

S = The sum of the time spent to deliver packets to each destination

N = The number of packets received by the all destination nodes

CONCLUSION

In this proposed system, we have successfully simulated novel and a practical scheme for awarding incentives for several probabilistic routing protocols in the opportunistic mobile network environment. We have integrated the proposed designed scheme and evaluated them using NS2 Simulator Tool. The evaluation results present the following observations:

- The nodes are behaving with full of cooperation under the proposed schemes
- This incentive schemes can substantially improve the nodes' delivery ratio (10.1-76.8%) in the presence of selfish nodes

RECOMMENDATIONS

Since, this research focuses on unicast probabilistic routingand the interesting direction of future research will be concentrating to design the system based on multicast and broadcast probabilistic routing. The collusion is also an increasing and important problem in mobile ad hoc networks. Another direction of future research will also be to design of collusion resistant probabilistic routing protocol in opportunistic mobile ad hoc networks.

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