A Game Theoretic Approach to Community based Data Sharing in Mobile Ad hoc networks

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Abstract— **Government interventions on usage of free speech for communication has been rising of late. The government of Iraq's ban on the Internet, ban of mobile communications in Hong Kong student protests highlight the same. Applications like Firechat which use mobile ad hoc networks (MANETs) to enable off the grid communication between mobile users, have gained popularity in these regions. However, there have been limited studies on selfish user behavior in community data sharing networks. We wish to study these data sharing communities using game theoretic principles and propose a normal form game. We model selfishness in community data sharing MANETs and define the rationality for selfishness in these networks. We also look at the impact of altruism in community data sharing MANETs and address the issue of minimum number of altruistic users needed to sustain the MANET. We validate the novel model using exhaustive simulations and empirically derive important observations.**

I. INTRODUCTION

The ramifications of mobile messaging applications in allowing a user to communicate freely with a large group of audiences using broadcast communication is significant. However, government interventions on usage of technology for communication has been rising of late.

Iraq's ban on the Internet [1] across the country, supposedly was a legal action taken to improve national security. However, shutting down of Internet services for civilians is a highly debatable issue. These civilians later resorted to Firechat [2], an application which creates a wireless mesh network of users and allows them to communicate with each other.

Similarly, during the Hong Kong protests in 2014 [3], the Chinese government officials banned the usage of mobile Internet and messaging services to hamper communication between protesters. Firechat was again used by the protestors to communicate with each other.

Closer home, India also witnessed a similar scenario during the Patel protests in August 2015 [4], held in Gujarat. As the protests turned violent, government authorities disabled mobile Internet and messaging services to disable broadcast communications.

Applications such as Firechat highlight the rise in mobile ad hoc networks [5] (MANETs), as a common everyday technology. A MANET, is defined as an infrastructure independent network of mobile devices which uses wireless technology to communicate with each other. Since the nodes in the network can move freely, the network topology of a MANET can keep altering continuously. This local network can also connect to the Internet. The study of MANETs has long assumed that all nodes in the network will actively participate in the communication between any two nodes in the system. However, in reality this may not be the case, since mobile phones which form the backbone of these networks are highly resource constrained. There is limited battery which can be used to communicate in the network. Limited memory and processor capacity also inhibit active involvement of nodes which enable communication between users. Routing of information is seen as a burden on the nodes, which can lead to selfishness among users in MANETs.

Given a community of mobile users who participate in sharing data between themselves, we want to analyze the impact of selfishness among users. This paper looks at a game theoretic approach to model users of the community as agents in a game, who are rational and wish to maximize their individual benefits. In this context, we analyze the effect of altruism [6] which is defined as a behavior in which any player incurs a cost and performs an action which benefits a third party in the system, but may or may not benefit the altruistic player. Our study looks at the importance of altruistic users in sustaining the system. We also look at the existence of alternate behaviors apart from selfish and altruistic natures. Using the proposed model, we define the rationality for selfish behavior among users. We validate our model using exhaustive simulations to analyze all possible behaviors of users in a MANET.

A. Contributions

In this paper, we investigate the following problems:

1) **Selfishness in Community Data Sharing MANETs**: We analyze a MANET in a community data sharing context, as a multi-agent system using Game Theory and define the costs and benefits associated with any user who participates in a data sharing MANET. We show selfishness is a rational behavior for any user in the system.
2) **Impact of Altruism in Community Data Sharing MANETs**: We look at the problem of existence of a minimum number of altruistic users in a community data sharing MANET, to sustain the MANET.
3) **Existence of alternate behaviors in Community Data Sharing MANETs**: We look at the possibility of alternative user behaviors in a community data sharing MANET apart from Selfish and Altruistic behaviors.

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By carrying out extensive simulations, we are able to empirically show the effectiveness of the novel model proposed in this paper. By defining various scenarios of interactions between users in a MANET, we are able to show the net benefit of the system differing in each of these scenarios. Our experimental results also provide key insights into addressing the presence of altruistic users in a community data sharing MANET. To the best of our knowledge, this is the first effort to analyze a MANET in a community data sharing context, as a multi-agent system using Game Theoretic principles. We are also the first to address the existence of minimum number of altruistic users in a community data sharing MANET to sustain the service.

B. Outline of the Paper

The rest of the paper is organized as follows, in Section 2, we highlight the relevant work related to file sharing in MANETs. The proposed Game theoretic model to analyze community data sharing in MANETs is defined in Section 3. This is followed by the simulation model for community data sharing in MANETs in Section 4 and results and discussion in Section 5. We conclude with a summary of the work done and directions for future work in Section 6.

II. Relevant Work

The problem of selfishness in mobile ad hoc networks is a well-studied one. There have been several approaches, which have been consolidated by Yoo and Agrawal in [8]. But, all existing game theoretic models use the concept of ranking or recommendation systems to facilitate sharing. As a generalization, active nodes which facilitate sharing in the mobile ad hoc network are ranked higher in the system. While serving a request, higher ranked nodes are preferred to lower ranked nodes. Thus, a node which is ranked higher will benefit more from the system. A detailed survey on application of game theory in ad hoc network is provided in [9], which also looks at the protocol aspects, waveform adaptation and routing.

To the best of our knowledge, this paper is the first work which tries to model the problem of community data sharing in MANETs, using game theoretic principles for analyzing the impact of selfishness and altruism of users.

III. Game theoretic model for community data sharing in MANETs

A. Types of Users

We first define the various types of users who can be part of a MANET for data sharing in a community. We assume that all users in the MANET have access to some files which belong to themselves and these can be shared with other users in the system. If any user wants to obtain any file from the network, the user will raise a request and any user who has this requested file will transfer the file to the user. We can have three different types of users as follows:

1) **Client or Destination**: A client is any user in the system who raises a request for a particular file. If the requested file is present with any user in the MANET, that particular user will initiate transfer of the file to the client. If multiple users in the system have access to the requested file, then we will always default to the shortest path possible to serve this client request.
2) **Router**: The range of communication in a MANET is limited to the technology adapted by the users in the system. If the users in the network use WiFi technology (IEEE 802.11) for communication, the range is between 100 - 200 meters. As a community mobile ad hoc network can span more than this range, we will require intermediate users called routers, to perform the function of routing of files from the server to the client.
3) **Server or Source**: A server in a community data sharing MANET, is any user who can serve a client request for a particular file. A server can serve multiple client requests.

B. Types of Behaviors

We define three possible user behaviors in a data sharing MANET:

1) **Selfish**: Selfish users participate in the system only to raise requests for files or act as clients only. They dont participate in the system as routers or as servers. They are non-cooperative agents in the system who dont contribute to the social good of the community.
2) **Altruistic**: Altruistic users are opposite in behavior to selfish users. They devote themselves to the welfare of other users in the system. They will actively participate in the system and serve file requests and enable routing of files.
3) **Reciprocative**: We found that there is a possibility to define a third behavior in this setting. A Reciprocative user is neither a selfish user nor an altruistic user. Reciprocating users take part actively in the system and serve file requests and enable routing of files, only as long as the file requests raised by these users are served by other users in the MANET. If their request is not satisfied, they will turn selfish.

C. Defining the Game

We define a normal form game G [6], to model the community data sharing problem in a MANET as G = (P, S, U), where P = $\{1, 2, ..., n\}$ is the set of players, S = $\{S_1$, S_2,..., $S_m\}$ is the set of strategies which can be utilized by any player to take part in the game, and U = $\{U_1$, U_2,..., $U_m\}$ is the set of utilities derived from S. S = $\{In, Out\}$, is the set of strategies available to a user indicating participation in the system.

1) **Benefits in the system:** The benefit or utility u gained by any user is directly proportional to the number of files received by the user. This is given as follows:

$$\sum_i u(f_i)$$

where, i indicates the files being received and f is the size of the file.

*2) **Costs in the system:*** The cost c or amount of resources consumed by a user, is directly proportional to the number of files being transferred. Denoting f as the size of file being transferred, b as battery used, m as memory used and p as processor used for transfer of files, we define two costs in the system as:

a) **Costs to routers:** For any user routing j files in the system, the cost incurred is:

$$\sum_j [b(f_j) + m(f_j) + p(f_j)]$$

b) **Costs to servers:** For any user serving k files in the system, the cost incurred is:

$$\sum_k [b(f_k) + m(f_k) + p(f_k)]$$

An important assumption we are making is that, for any user in the system, the benefits derived from the system significantly exceeds the costs involved for taking part in the system. In other words, for any user we have $u > c$. [1]

D. Selfish Rationale

We define the net utility of a user, as the difference between benefits gained and costs incurred. Thus,for any user to stay and actively participate in the system, the user must derive positive net utility, i.e.,

$$\sum_i u(f_i) \geq \sum_j [b(f_j)+m(f_j)+p(f_j)] + \sum_k [b(f_j)+m(f_j)+p(f_j)]$$

Assuming unitary file size across all users, we have:

$$(i * u) \geq [(j * (b + m + p)) + (k * (b + m + p))]$$

or,

$$(i * u) \geq [(j + k) * (b + m + p)]$$

This will always be true if any user acts as a client only and never takes part in the system as a router or a server, resulting in the RHS of the above equation to be zero, thus, $(i*u) > 0$. Therefore, any user is highly incentivized to become selfish to maximize his/her individual benefit by deriving an utility of:

$$\sum_i u(f_i) \geq 0$$

E. Selfish user vs. Altruistic user

Let us look at the utility derived by a selfish user and an altruistic user in a data sharing MANET. The payoff matrix for this case is given in Table I.

The utility for the selfish user is u. The utility for altruistic user is $-c$ as it incurs a cost in serving the file. If either of the selfish or altruistic users dont participate in the system, then the utility derived for either of them is 0.

[1]In an informal survey conducted in an educational institute comprising of a mix of students and professors, we noticed a similar behavior where users associated a significantly higher value to the benefits as compared with the costs associated to acquire a file in the network.

TABLE I
SELFISH USER VS. ALTRUISTIC USER PAYOFF MATRIX

Selfish \ Altruistic	In	Out
In	$u, -c$	$0, 0$
Out	$0, 0$	$0, 0$

The dominant strategy Nash equilibrium [2] for the game is (In, Out) whose payoff is $(0, 0)$. Thus, at equilibrium, the selfish user derives no utility due to his/her selfish behavior.

Let us say that the selfish user is willing to transfer the costs borne by the altruistic user to the altruistic user, to ensure that the altruistic user takes part in the system. Now, the selfish user will derive a net utility of $u - c$ The utility for the altruistic user is zero. But, there is no dominant strategy Nash equilibrium for the game as the altruistic user is indifferent to In and Out strategy as it incurs zero utility in both cases.

Now, let us say that the selfish user is willing to transfer an additional epsilon ϵ value to the altruistic user. Thus, the selfish user will derive a net utility of $u-c-\epsilon$ and the utility for the altruistic user is ϵ. From our initial assumption and footnote[1], we can safely assume the net utility to the selfish user to be positive. The new payoff matrix is given in Table II. The dominant strategy Nash equilibrium for the game is (In, In) whose payoff is $(u - c - \epsilon, \epsilon)$.

TABLE II
SELFISH USER VS. ALTRUISTIC USER PAYOFF MATRIX

Selfish \ Altruistic	In	Out
In	$u - c - \epsilon, \epsilon$	$0, 0$
Out	$0, 0$	$0, 0$

F. Selfish user vs. Reciprocative user

Assuming the probability with which the reciprocative user remains reciprocative is p and with a probability $(1 - p)$, the reciprocative user turns selfish. The payoff matrix in this case is given in Table III. The dominant strategy Nash equilibrium for the game is (In, In) whose payoff is $(p(u - c - \epsilon), p\epsilon)$.

TABLE III
SELFISH USER VS. RECIPROCATIVE USER PAYOFF MATRIX

Selfish \ Reciprocative	In	Out
In	$p(u - c - \epsilon), p\epsilon$	$0, 0$
Out	$0, 0$	$0, 0$

G. Reciprocative user vs. Altruistic user

The utility for both the users is given by $u - c$. The payoff matrix in this case is given in Table IV. The dominant

[2]A dominant strategy Nash equilibrium [6] is defined as an equilibrium in which each players chosen strategy is a dominant strategy, which is optimal and doesn't depend on the choice of other players strategies in the system. There is no incentive for the player to deviate from his/her dominant strategy. The payoff is maximum for each player at the dominant strategy Nash equilibrium.

strategy Nash equilibrium for the game is (In, In) whose payoff is $(u - c, u - c)$.

TABLE IV
RECIPROCATIVE USER VS. ALTRUISTIC USER PAYOFF MATRIX

		Altruistic	
		In	Out
Reciprocative	In	$u-c, u-c$	$0, 0$
	Out	$0, 0$	$0, 0$

H. Altruistic user vs. Altruistic user

In this case, as both the users in the system are altruistic in nature, the utility for each user will be $u - c$. The dominant strategy Nash equilibrium for this game is (In, In) and the payoff is $(u - c, u - c)$.

I. Reciprocative user vs. Reciprocative user

In this case, the dominant strategy for both the reciprocative users will be In, indicating both the users would participate in the system actively. The dominant strategy Nash equilibrium for this game is (In, In) and the payoff is $(u - c, u - c)$.

J. Selfish user vs. Selfish user

In this case, as both the users are selfish, there will be no transfer of files in the system. There is no dominant strategy Nash equilibrium in this game.

Thus, using our model, we have covered all possible interactions which can exist in a community data sharing MANET based on various possible user behaviors.

IV. SIMULATION MODEL FOR COMMUNITY DATA SHARING IN MANETS

We define three types of games to capture the intricacies in the system. In each of these, the final threshold on resources indicates the point beyond which any node would exit the system. A money attribute is used to capture the monetary transfers in the system. For our simulations we will be using an important result by Guo et al. in [7], which states that the degree distribution of nodes in a MANET follows binomial distribution. The types of games are:

1) **Game Type 1**: In this game, altruistic users play out the game till they reach their final threshold. There is no conversion of altruistic users to selfish users.
2) **Game Type 2**: In this game, altruistic users will convert to selfish users beyond a particular conversion threshold, when they realize they are taking part actively in the system, but still have not gained benefits.
3) **Game Type 3**: In this game, we consider the scenario when selfish users have no money to take part in the system. We allow the selish users to convert to altruistic users and serve file requests and generate money to take part in the system.

The model for evaluating community data sharing in a MANET is described as algorithm 1. We are given the number of users in a community data sharing MANET N, number of selfish users N_S, number of altruistic users N_A, number of reciprocative users N_R, the final threshold for resources T, threshold beyond which altruistic users convert to selfish users T_A, and the number of simulations $\#_S$ for which the algorithm is to be run. In each simulation run, we generate a graph with N nodes and initialize the node level attributes such as battery, memory, processor and money. We activate certain selfish, altruistic and reciprocative nodes based on N_S, N_A and N_R. We generate random edges in G based on binomial node degree distribution. We select random source and destination nodes and compute the shortest path without a selfish node between them. The client/destination node makes payments for costs incurred to server and routers in the path. Server and router nodes reduce the amount of resource available with them. Any node which has exhausted its resources, will be removed from the system. We compute the average net benefit as the number of files transferred in the system.

Algorithm 1 Modeling community data sharing in a MANET

Require: Number of users in community data sharing MANET N, Number of selfish users N_S, Number of altruistic users N_A, Number of reciprocative users N_R, Final threshold for resources T, Threshold beyond which altruistic users convert to selfish users T_A, Number of simulations $\#_S$

for i = 0 to $\#_S$ **do**
  Generate an empty Graph G with N number of nodes
  Initialize node level attributes: battery, memory, processor, money
  for j = 0 to N_S **do**
    Activate selfish nodes in G
  end for
  for j = 0 to N_A **do**
    Activate altruistic nodes in G
  end for
  for j = 0 to N_R **do**
    Activate reciprocative nodes in G
  end for
  Generate edges in G
  Src = Generate random source from G, $Dest$ = Generate random destination from G, $Path$ = Shortest path between Src and $Dest$
  if destination node is reciprocative and unable to retrieve file requested **then**
    Reciprocative destination node converts to selfish node
  end if
  Client/Destination node makes payments for costs incurred to routers and server based on the behavior of these nodes
  Routers and server nodes reduce the amount of resources available
  for each router node in $Path$ **do**
    if resources available with router node $\leq T$ **then**
      Router node is removed from the system
    end if
  end for
  if source node is altruistic and resources available with source node $\leq T_A$ and Game type = 2 or 3 **then**
    Altruistic source node converts to a selfish node
  end if
  if resources available with source node $\leq T$ **then**
    Source node is removed from the system
  end if
  if money remaining with destination node = 0 **then**
    Destination node is removed from the system
  end if
  if destination node is selfish and has no money left and Game type = 3 **then**
    Selfish destination node converts to altruistic node
  end if
end for
Compute average net benefit, given by number of files transferred in the system

A. Simulation Parameters

We simulated the node degree distribution in a community data sharing MANET by considering an area of 2 square kilometer denoting a community and the WiFi range of mobile devices to be 200 meters. In this scenario, we

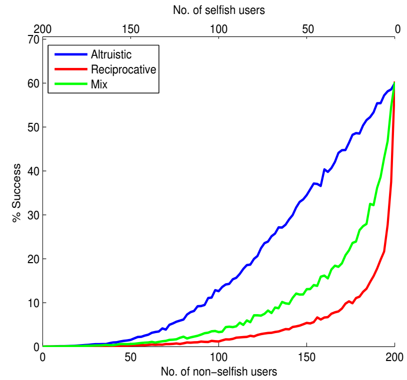

Figure 1: Success % in Game 1

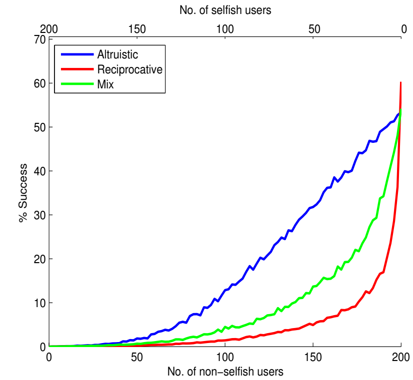

Figure 2: Success % in Game 2

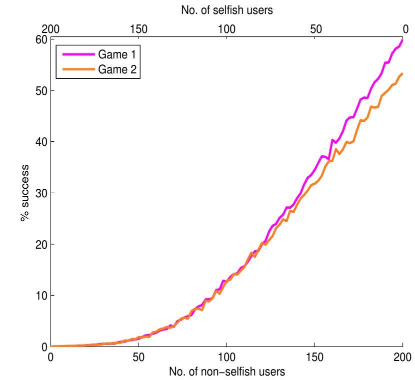

Figure 3: Altruistic behavior across games

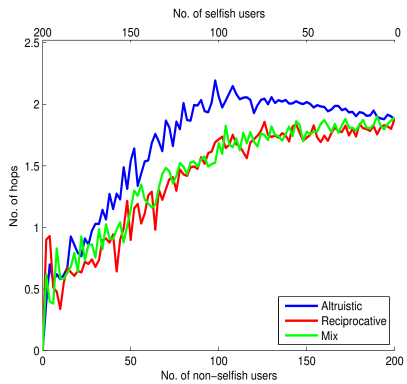

Figure 4: Average no. of hops for file transfer

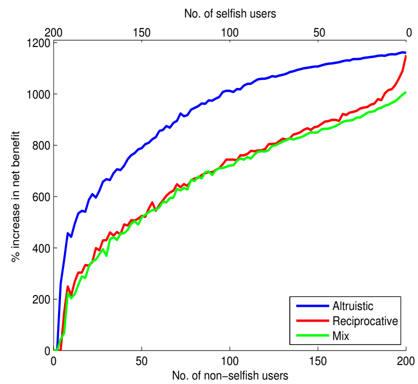

Figure 5: % Change in net benefit

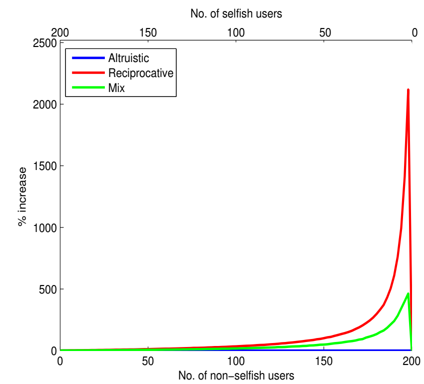

Figure 6: % Increase in selfish users

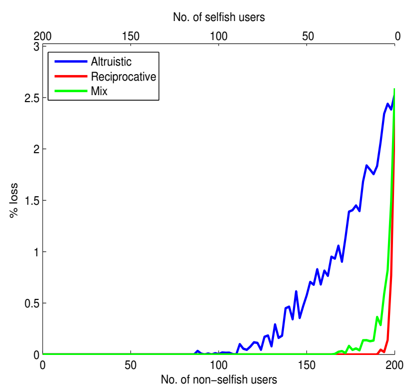

Figure 7: % Loss due to exhausted users

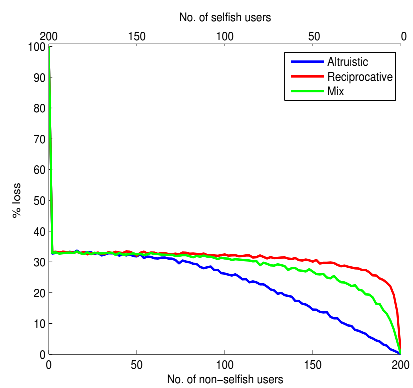

Figure 8: % Loss due to selfish users

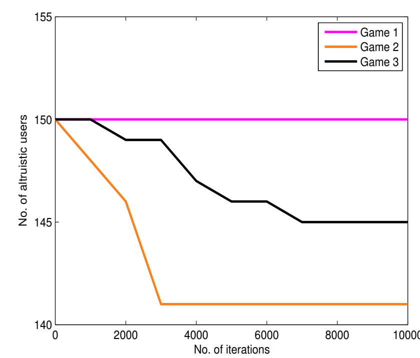

Figure 9: Change in no. of altruistic users

randomly placed nodes across the chosen area. We found the node degree distribution was binomial, with the probability of existence of a link between any two nodes given by 0.2. We will be using the same for our simulations.

To validate the proposed model, we ran 150,000 unique iterations with 200 users. Each iteration consists of 1,000 file requests. This gives us a confidence level of 95% for the results. The language used for simulating the model was C++ along with Boost Graph Libraries. The experiments were carried out on a quad core Intel i3 processor, with 4 GB of RAM on Ubuntu linux operating system. The final threshold value was 10%, which means, if any user in the system has used up 90% of the resources available, it will exit the system. The altruistic conversion threshold was 30%.

B. Dataset composition for simulations

For simulations, we start with 200 selfish users in the system and reduce the number of selfish users and increase non-selfish altruistic and reciprocative users in the system for each consecutive simulation iteration. This is denoted in Table V.

	Number of selfish users	**Number of non selfish users**
First simulation run	200	0
	199	1
	.	.
	1	199
Last simulation run	0	200

TABLE V

COMPOSISTION OF DATASET FOR SIMULATIONS

V. Results and Discussion

Success Percentage in retrieving files in game 1: For plotting the graphs, we denote the number of non-selfish users along the primary x-axis, the number of selfish users along the secondary x-axis and the success percentage along the y-axis. There is a linear increase of success percentage in retrieving files with increase in altruistic users (See Figure 1). This linear relationship, indicates there is no minimum number of altruistic users in the system which can be used to maximize net benefit. With Reciprocative users in the system, see a sharp increase in the success percentage, when the ratio of reciprocative users in the system is around $9/10^{th}$ the number of users in the system. Using these plots, one can derive the ideal user combination in a data sharing MANET to achieve a certain level of service level indicated by the success percentage.

Success Percentage in retrieving files in game 2: We find that the success percentage in retrieving files follows a similar pattern as in game type 1 (See Figure 2). However, in this case, the success percentage from having only altruistic users is significantly lower than success percentage from having only reciprocative users in the system. This can be attributed to the conversion of altruistic users to selfish users in game type 2.

Altruistic behavior across game types: On comparing the success percentage from having altruistic users in the system between game types 1 and 2 (See Figure 3), we find that there is a significant divergence between the two plots as the number of altruistic users increases in the system. In game type 2, as the number of altruistic users increases, the conversion of altruistic to selfish users increases, thereby, decreasing the net benefit in the system.

Average number of hops for file transfer: When we observe the average number of hops required to transfer a file (See Figure 4), we find that as the number of non-selfish users increases in the system, the number of hops also increases. This indicates, with higher non-selfish users, we can have a greater reach in the system. The plots were similar across game types.

Percentage change in net benefit: As indicated in figure 5, the percentage increase in net benefit in the system follows diminishing returns, i.e., as we incrementally increase the number of non-selfish users in the data sharing MANET, there is a decrease in marginal percentage increase of net benefit in the MANET. The plots also indicate that having alturistic users in the system is marginally better than having reciprocative users in the system. The plots were similar across game types.

Percentage increase in selfish users: As the number of selfish users in the system approaches 0 at the beginning of the iteration, there is a significant increase in the percentage of selfish users at the end of the iteration (See Figure 6). This is primarily due to the conversion of non-selfish users to selfish users during the simulation run. We also find that the increase in selfish users is as high as 2000% when we have reciprocative users in the system. The plots were similar for game types 2 and 3.

Percentage loss due to exhausted users: Figure 7 shows the percentage loss in net benefit of the system due to the presence of exhausted users in the path chosen for transfer of files. If any user's resources such as battery goes below the final threshold value, they exit the system. By doing so, these exhausted users reduce the net benefit of the system. We found that, there can be as much as 2.5% loss in the system due to these exhausted users. We also found that the percentage loss due to exhausted users is higher if we have altruistic users in the system compared to reciprocative users or mix of both. This indicates, the rate at which nodes get exhausted is higher if a system has only altruistic users.

Percentage loss due to selfish users: We plotted the percentage loss in net benefit of the system due to the presence of a selfish user in the shortest path chosen from source to destination while serving the file request (See Figure 8), we found that there is sharp decrease in the percentage loss with the presence of a minimal number of non-selfish users in the system. We also found that the percentage loss due to selfish users in the path chosen to transfer files is lower if we have altruistic users in the system. The plots were similar across game types.

Change in number of altruistic users: Denoting one simulation run with 50 selfish users and 150 altruistic users (See Figure 9), if we observe the change in the number of altruistic users across iterations, we find that there is a sharp decrease in altruistic users in game type 2 when compare to other game types. In game type 3, as we allow the conversion of selfish users to altruistic users based on certain conditions, we can see that the decrease in altruistic users is lesser than game type 2. There is no change in altruistic users in game type 1 as expected.

VI. Conclusions and Future Work

In this work, we have proposed a novel game theoretic model to analyze community data sharing in MANETs. Using this model, we are able to analyze selfishness in a community data sharing MANET and also define selfish rationality of any user in the system. We also looked at various possible behaviors which can exist in this network. With exhaustive simulations on a community data sharing MANET, we are able to empirically answer critical questions, such as impact of altruistic users in this system and existence of a minimum number of altruistic users to sustain the MANET.

As future work, we plan to explore Altruistic punishment [10] which is based on Evolutionary Game Theory and employs a third party punishment mechanism to increase cooperation between users in the system.

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