Internal Threats Avoiding based Forwarding Protocol in Social Selfish Delay Tolerant Networks

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Abstract—In traditional delay tolerant networks (DTNs), there exists a potential assumption that the nodes are willing to help others for packet forwarding. However, in the real application scenarios, such as civilian DTNs, selfish behaviors always widely exist. Therefore, the assumption that nodes are cooperative is not realistic in all applications. Currently, most of the existing incentive mechanism focuses on individual selfish behaviors. Few research work is proposed on social selfish behavior in DTNs. In this paper, we stimulate the nodes to cooperate with others by using a virtual bank mechanism. This incentive mechanism can effectively avoid individual selfish behaviors. Meanwhile, we observe that under this individual selfish incentive mechanism, the social distribution is unfair. That means the poverty nodes would appear in the networks, and become the internal threats for the social DTNs. To avoid this, we introduce the Gini coefficient to measure the inequality of the social distribution. Furthermore, by using the taxation strategy, we avoid the internal threats caused by social selfishness. To demonstrate the selfish behavior, we introduce the forwarding protocol which is based on social relations of nodes. We verify the proposed methods using simulation evaluations.

I. INTRODUCTION

Compared with traditional wireless networks, in delay tolerant networks (DTNs), contemporaneous path between the source and destination nodes may not exist within given time [1]. Also, the packets generated in DTNs are opportunistically forwarded to the destination. Generally speaking, most of the existing forwarding algorithms assumed that the nodes are cooperative and willing to help others to forward packets. However, in the real application of DTNs, the nodes are rational, such as PeopleNet [2] and Pocket Switched Network [3]. Since the nodes are rational, they would like to consider how to maximize their own utility instead of network-wide criteria. This is the so-called selfish behavior in social delay tolerant networks. Since the selfish behavior widely exists, it results in serious performance degradation for DTNs [4].

There are two categories of selfish behaviors in social DTNs, individual selfishness and social selfishness [5]. Towards the current research results of selfish behavior in DTNs, most of them address the issue of individual selfishness [6,7]. As for the nodes which are under individual selfishness, they want to get help from others but do not want to help others, to maximize their own utilities. The existing algorithms focus on addressing the individual selfish behavior such as using reputation-based [8], credit-based [9,10], or game theory-based [11] approaches to stimulate the nodes to cooperate and forward packets for others. The core idea of these incentive mechanisms is to let the nodes know that if they are cooperative, they would get utility. Further, the more help they give to others, the more utility they would obtain. It is easy to see that these incentive mechanisms are effective for avoiding individual selfishness. However, as for the incentive mechanism for solving the selfish behavior, the potential assumption is that the status of nodes is equal in social DTNs. Obviously, this is an impossible assumption in the real world. In more realistic social DTNs, if the nodes have to offer forwarding service for others, they prefer to serve those who have social relations (e.g., friendship [12], roommate) with them. The relations will be strengthened through helping each other. On the other hand, for the nodes without any relations, they prefer to ask the influential (mighty) nodes to help them for forwarding packet. The influential nodes are defined as the nodes with more social relations. Above preferences imply social selfishness.

In this paper, we stimulate the nodes to provide the service of packet delivery for others by introducing the concept of virtual bank which takes charge to distribute the reward to the participant nodes in the packet forwarding process. We refer to reward as virtual money, and consider that every node in the DTNs could be the source, destination and relay node. There are two basic principles in the virtual bank:

- If the nodes help others to forward the packet to the destination successfully, they will get the reward from the source nodes.
- All the nodes are trying to pursuit the reward to ensure they have enough virtual money for paying the forwarding process.

However, the social selfishness will have negative impact on DTNs, which is analyzed as follows. Typically, in order to guarantee the packet could be forwarded successfully within a given time, the nodes prefer to choose those having more social relations to request packet forwarding services. Due to
the critical gaps existing among the social relations of different nodes, some nodes with more social relations will get more opportunities to help others, and thus obtaining more rewards according to the existing of incentive mechanism for individual selfishness. On the contrary, the nodes which have less social relations will be hard to get rewards. With time pass by, those starving nodes with less social relations cannot afford the cost for forwarding. We refer to those nodes falling into the poor status as poverty nodes. As for these poverty nodes, because they have been isolated by the DTNs, some of them have higher probability to become the malicious nodes and try to destroy the network performance. In this paper, these nodes are identified as the internal threats for the social selfish DTNs. To the best of our knowledge, this is the first paper to discuss the internal threats caused by social selfishness for DTNs.

To solve the issue of internal threats, we introduce the Gini coefficient [13] to measure the social distribution for DTNs, it is used as a measure of inequality of income or wealth in the real world. Through the different Gini coefficient, we adopt the taxation strategy to re-distribute the social virtual money to avoid the appearance of the poverty nodes. In this way, we can avoid the internal threats, which are caused by social selfishness. Furthermore, we introduce our forwarding strategy, which is based on the social relations of the nodes. The main contributions of this paper include the following aspects:

- Analyze personal selfishness and social selfishness
- Identify the problem caused by social selfishness, and introduce virtual bank
- Propose the internal threats caused by social selfishness
- Propose solution to alleviate the internal threats

The remainder of this paper is structured as follows. Section II presents the problem statement of this paper. Section III gives the detailed for internal threats avoiding mechanism for social selfish DTNs. Section IV introduces our forwarding strategy and section V shows simulations and discusses the results. Section VI concludes the paper with future work.

II. PROBLEM STATEMENT

A. Network Model

In social delay tolerant networks, researchers have introduced some incentive mechanism for avoiding the individual selfish behavior. In this paper, we stimulate the nodes to cooperate and willing to help others for forwarding packets by using the virtual money payment mode. In the initial phase, we let each node possesses the same amount of virtual money. When the node asks others to forward his own packet to the destination, the node needs to pay the virtual money to the relay nodes that help him to forward the packet. To guarantee their own packets could be forwarded by others, all the nodes are trying to pursue the virtual money instead of keeping selfishness. To ensure the virtual money could be distributed in time, we introduce the virtual bank to achieve this goal.

In this paper, we set some fixed position nodes and named them as base station. The communication radius of the base stations is larger than the normal nodes. Any two adjacent base stations can communicate directly. All the base stations cover the entire network and it is shown in Figure 1. These base stations constitute the virtual bank. Furthermore, we assume these base stations can exchange their information in the real-time mode. The virtual bank maintains the information for all the moving nodes belonging to the network. The information includes: node ID and the virtual bank account. If there are some new nodes join the network, the virtual bank will distribute some initial virtual money into their account to ensure they can acquire the forwarding service from others immediately. In Figure 1, we can see that node $S$ generates packet and the destination is node $D$. The packet will be forwarded by others. Because of the payment incentive mechanism, node $S$ needs to know which node helped him. Therefore, node $S$ will insert a special field into the packet to record which nodes participate in the forwarding process. When the destination node $D$ received the packet generated by node $S$, node $D$ informs the base station when it first encountered. The virtual bank deducts the forwarding cost from the account of node $S$ and transfer the virtual money to the forwarding nodes accounts.

B. Security Problem Caused by Internal Threats in social DTNs

By introducing the incentive mechanism of virtual bank, the individual selfishness could be avoided in the social DTNs. However, as we have previously described, in a real application scenario, the social selfish behavior is more general and difficult to avoid. To the best of our knowledge, there is no existing research results that can avoid the social selfish behavior in DTNs. Actually, we think there is no need to avoid the social selfish. In our work, we analyze the influence of social selfishness and try to minimize its influence. As for the existing incentive mechanism for individual selfishness, the general idea is let the nodes know, the more work they do for others, the more payoff they will get from others. That means the payment is related to
how much forwarding work they had participated in. Toward the source nodes in DTNs, they prefer to choose the relay nodes which have more social relations to forward their packets since the social selfishness existing in the networks. The nodes which have more social relations have higher probability to encounter other nodes within their own social relation, and the higher encounter probability can reduce the delivery delay for packets. Therefore, to guarantee the network performance, we should encourage the social selfish behavior. In such case, the nodes which have more social relations, will have more opportunity to help others. Based on this, these nodes will get more social payoff (virtual money). On the contrary, nodes which have less social relations, will have the less opportunity to participate in the forwarding process. For them, it is difficult to get social payoff. The necessary condition successful for packet transmission is payment. For the nodes, which have less social relations, they will become the poverty nodes as the time pass by. Then, no node would like to cooperate with them. These nodes will be isolated by the social DTNs.

In the aspect of social selfish DTNs security issue, we divide the network threats into two categories: external threats and internal threats. In our work, we will concentrate the internal threats, which are caused by the social selfishness. The internal threats, which are mentioned in this paper, are caused by the internal nodes of the network. These nodes are normal and would like to serve for the network. However, due to their social relations, when they turn into the poverty nodes, some of them will become the malicious nodes. Since these internal malicious nodes exist in the network, it is more difficult to detect their malicious behavior. To the best of our knowledge, this is the first paper to address the internal threats, which is caused by the incentive mechanism for individual selfishness in social selfish DTNs.

III. GINI COEFFICIENT AND TAXATION STRATEGY BASED INTERNAL THREATS AVOIDING MECHANISM

A. Gini coefficient and the Stability of Social DTNs

In order to avoid the issue of internal threats caused by the social selfishness, we need to solve the problem of uneven social wealth (virtual money) distribution. In this paper, we introduce the Gini coefficient to measure the social wealth distribution and use the taxation strategy to re-distribute the social wealth for the network.

The Gini coefficient measures the degree of concentration (inequality) of a variable in a distribution of its elements. It compares the Lorentz curve of a ranked empirical distribution with the line of perfect equality. This line assumes that each element has the same contribution to the total summation of the values of a variable. The Gini coefficient can range from 0 to 1; it is sometimes multiplied by 100 to range between 0 and 100. A low Gini coefficient indicates a more equal distribution, with 0 corresponding to complete equality, while higher Gini coefficients indicate more unequal distribution, with 1 corresponding to complete inequality. To be validly computed, no negative goods can be distributed. Thus, if the Gini coefficient is being used to describe household income inequality, then no household can have a negative income. When used as a measure of income inequality, the most unequal society will be one in which a single person receives 100% of the total income and the remaining people receive none (G = 1); and the most equal society will be one in which every person receives the same income (G = 0).

Based on the above explanation for Gini coefficient, it is easy to see that uneven social distribution could lead the Gini coefficient increasing to a higher level. In the social DTNs, the main reason for uneven social distribution is the social selfishness. As we know, in the real human society, if the Gini coefficient is in a higher level, it means that the society is in the unstable status, e.g., criminal activity will occur frequently. This phenomenon of human society also exists in social DTNs. In this paper, the unstable social DTNs means that the internal threats exist in the network. To avoid the internal threats caused by uneven social distribution, we use the virtual bank to re-distribute the social distribution through the taxation strategy. Furthermore, this strategy also reduces the Gini coefficient for the social DTNs.

B. Calculating Gini coefficient for Social DTNs

As mentioned in the above section, we introduce the virtual bank to distribute the virtual money for forwarding process. Since the virtual bank maintain IDs and the accounts for all the nodes, we can use the virtual bank to calculate the Gini coefficient for the social DTNs. The following is the calculation process of Gini coefficient.

In Figure 2, we define the Gini coefficient by the following equation.

\[ G = \frac{S_A}{S_{A+B}} \]  

(1)

From eq. (1), we can see that it is difficult to calculate the Gini coefficient only using the Lorentz curve. Therefore, we make the following conclusion and it is given by the following Equation 2.

\[ \Delta G = \frac{\sum_{j=1}^{n} \sum_{i=1}^{n} |Y_j - Y_i|}{n^2}, \quad 0 \leq \Delta G \leq 2u \]  

(2)
Here, $\Delta G$ is the Gini mean difference, $|Y_j - Y_i|$ is the payoff difference of any two nodes, $n$ is the number of nodes in the network. $u$ is the payoff mean value for all the nodes. Furthermore, we define the following equation:

$$ G = \frac{\Delta G}{2u}, \quad 0 \leq G \leq 1 \quad (3) $$

We have proven that $G = \Delta G/2u = 2S_A$, the following are the details. In the first step, we calculate the expression of $G = \Delta G/2u$. Here, $Y_1, Y_2, \cdots, Y_n$ is the descending sequence of the payoff of all the $n$ nodes. Then we have the following decomposition expression and it is shown in Equation 4.

$$ \sum_{j=1}^{n} \sum_{i=1}^{n} |Y_j - Y_i| = 2 \times \sum_{i=1}^{n} [(i - 1) \times Y_i + (n - i) \times (-Y_i)] = 2 \times \sum_{i=1}^{n} [(2i - n - 1) \times Y_i] \quad (4) $$

For $\Delta G$, we have the following Eq. 5.

$$ \Delta G = \frac{\sum_{j=1}^{n} \sum_{i=1}^{n} |Y_j - Y_i|}{n^2u} = \frac{2}{n^2u} \times \sum_{i=1}^{n} [(2i - n - 1) \times Y_i] \quad (5) $$

Based on Equation 5, we have the following:

$$ G = \frac{\Delta G}{2u} = \frac{\frac{2}{n^2u} \sum_{i=1}^{n} [(2i - n - 1) \times Y_i]}{2u} \quad (6) $$

To express $G$ more clearly, we show the expression of $u$ as the following Eq. 7.

$$ u = \frac{Y_1 + Y_2 + \cdots + Y_n}{n} = \frac{\sum_{i=1}^{n} Y_i}{n} \quad (7) $$

By combining Equation 6 and 7, we have the following expression of $G$, and it is shown by Equation 8.

$$ G = \frac{\sum_{i=1}^{n} [(2i - n - 1) \times Y_i]}{n \times \sum_{i=1}^{n} Y_i} = \frac{\sum_{i=1}^{n} [(2i - n - 1) \times Y_i]}{n \times \sum_{i=1}^{n} Y_i} \quad (8) $$

In the second step of our proof, we introduce $G'$ to denote the $S_A/S_{A+B}$. In the right part of Figure 2, we can calculate the area of the $p$th piece. In the left part of Figure 2, we have $Y_0 = 0$ and $X_0 = 0$. The area of the $p$th piece can be shown by Eq. 9.

$$ S_p = \frac{1}{2} AB \times (AC + BD) = \frac{1}{2} \times \frac{1}{n} \times \left[ \sum_{j=1}^{p} Y_j \right] + \left[ \sum_{j=1}^{p} Y_j \right] \quad (9) $$

Through the calculation process of $S_p$, we can conclude the expression of $S_A$ and $S_{A+B}$. In this way, we conclude the following expression toward $G'$.

$$ G' = \frac{S_A}{S_{A+B}} = \frac{\sum_{p=1}^{n} \left[ \frac{(n+1) \times Y_p - 2 \times \sum_{j=1}^{p-1} Y_j} {2u \times \sum_{j=1}^{n} Y_j} \right]} {n \times \sum_{j=1}^{n} \left[ (2p-n-1) \times Y_j \right]} \quad (10) $$

By comparing $G$ and $G'$, we prove that $G = \Delta G/2u = 2S_A$. Based on equation 1, we have $G = S_A/S_{A+B}$. Since $S_{A+B} = 1/2$, $G = 2S_A$. Therefore, we can conclude that the $G$, which in Equation 2, is the Gini coefficient. By combining equation 2 and 3, we have the Gini coefficient calculation method, which is shown in equation 11.

$$ G = \frac{1}{2u} \sum_{i=1}^{n} \sum_{j=1}^{n} |Y_j - Y_i| \quad (11) $$

C. Taxation strategy based internal threats avoiding mechanism

In this paper, the virtual bank calculates the Gini coefficient of the network periodically. Based on the different Gini coefficient, the virtual bank executes different taxation strategies for the nodes. We only focus on three intervals of the Gini coefficient value, because that is enough to measure and control the wealth distribution for social DTNs. The three intervals are: 0.2 to 0.3, 0.3 to 0.4 and 0.4 to 0.5. When the Gini coefficient value is within the interval of 0.2 to 0.3, that means the social distribution of the network is relatively evenness. In such case, the virtual bank executes the following taxation strategy. The virtual bank deducts 10% of forwarding payoff for all the nodes to ensure initial distribution for new joining nodes. When the Gini coefficient value goes to the interval between 0.3 to 0.4, the social distribution is becoming uneven. We need re-design the taxation strategy. The virtual bank examines the account of all nodes and concludes the mean value of the virtual money. Toward the nodes which virtual money is above the mean value, the virtual bank deducts 15% of forwarding payoff. The rest of nodes keep the 10% taxation strategy. If the Gini coefficient value goes to the interval between 0.4 and 0.5, the virtual bank stops levy tax from the nodes whose virtual money is less than the mean value. As for the nodes which their virtual money is larger than mean value, the virtual bank still levy 15% of their forwarding payoff as the tax. Furthermore, as known from the Pareto principle, the virtual bank levies the punitive tax for some special nodes. Through the Pareto principle, we know that the 80% of the social wealth is owned by 20% of the population. Obviously, this principle also works in social selfish DTNs. The special nodes levied by the punitive tax are the 20% nodes in the DTNs. The virtual bank levies 30% of their payoff as tax.
account of the nodes which have the less social relations. In case, the virtual bank notices that the virtual money of an account is not enough for paying forwarding cost, the virtual bank affords the initial money to this account from the taxation income. This can guarantee this node still can survive in the network and if the node has enough virtual money for paying, it will not become the malicious node.

IV. ENABLING SECURE PACKET FORWARDING BY USING INTERNAL THREATS AVOIDING MECHANISM

In social selfish DTNs, we think each node has its own social relations and it maintains the social relations in some way. In this paper, the forwarding strategy of packet which we introduced is based on the social relations of nodes. We think the nodes are walking in a specific field (e.g., campus of university). When two nodes encounter and they have social relations with each other, they exchange the social relation map of their own. It means that as for a node, after exchanging the social relations map with its social relations members, it knows the social relations which belong to its social relations members. Based on the social relations of nodes, we design the packet forwarding strategy. When a packet is generated by the source node, firstly, the source checks its own social relations map. If the destination is in its own social relations, the source delivers the packet to the destination directly. If not, it checks the social map of its own. In the case that the destination is in the social relations of the social relations member of the source, the source asks the social relations member to forward the packet. If the source cannot find the destination within its social relations map, it asks the nodes which it encountered. In our forwarding strategy, the forwarding decision is a two-way choice process. Firstly, if the social relations of the encountered node is more than those of source, the source asks the encountered node to forward the packet. Secondly, the encountered node makes the final decision of whether it will forward. Because if too many nodes participate in the forwarding process, the payoff will be equally divided into several portions and also based on the limited buffer of node. In such case, the encountered node will refuse to forward this packet, despite the fact that the destination is in its social relations map, because the packets need to be forwarded by too many hops. As for the source node, if the encountered node refuses to forward, the forwarding decision will be executed again when it encounters the other nodes.

V. SIMULATION RESULT

A. Experiment Setup and Simulation Metrics

Our simulation is based on the MIT Reality trace [14]. In MIT trace, there were 97 students and staff which carry Nokia smart phone in MIT campus over nine months. These smart phones run bluetooth device discovery every five minutes and log more than 100 thousand contacts with each other. We use the contacts to perform trace-driven simulations. In MIT Reality trace, the dataset not only logs the contacts, but also logs the phone calling history for all the 97 phones. In our simulation, we assume that, as for any two nodes, if they had phone calling history, they have social relations with each other. As we mentioned in the previous section, our forwarding strategy is based on the social relations of nodes. Therefore, we use the phone calling history among the 97 nodes as the social relations.

In this section, each node generates one packet per day and assigns the destination within the 97 nodes randomly. The packet size is 20 KB and the TTL of packet is 100 days. Each node was given 10 units virtual money and one packet needs 1 unit for forwarding payment. The virtual bank exchange accounts of nodes per day.

We use the following metrics to evaluate the internal threats which we proposed. Firstly, we compare the Gini coefficient under the taxation strategy and non-taxation strategy, respectively. Second, we compare the payoff of the nodes which also under the taxation and non-taxation cased, respectively. The simulation results show that the internal threats exist in the social selfish DTNs widely. By using the Gini coefficient and taxation strategy which we proposed, we can avoid the social selfish issues for DTNs.

B. Simulation Results

In Figure 3, we can see that under the incentive mechanism for individual selfish, if the taxation strategy is not applied for the DTNs, the Gini coefficient of network increases to a high level within a short time period. In the time interval of 30 days to 50 days, the increasing rate is higher. The
main reason is, more and more packets are forwarded to the destination successfully. Also the more payoff of forwarding is distributed to the relay nodes. In the time interval of 50 to 100 days, the changing rate of Gini coefficient is becoming slower. This is because some nodes have no virtual money to pay and have been isolated. In the time point of \( T_{th} \) day, the Gini coefficient has broken 0.4, that means the social DTNs is in unstable state. Since the poverty nodes exist, the internal threats appear in the social DTNs. In the case that the taxation strategy is used, before 40 days, the Gini coefficient also increased quickly, this is because when the Gini coefficient is below 0.2, there is no taxation strategy are used for the nodes. When the Gini coefficient goes above 0.2, we adopt different taxation for different Gini level. Since the taxation re-distributes the social wealth and affords the initial virtual money to the poverty nodes, the gap between influential nodes and poor nodes is reduced. Therefore, the increment of Gini coefficient is controlled effectively.

Figure 4 shows the virtual money of node account under the instance of non-taxation strategy. We choose the mean value of the virtual money of the top 10 nodes and the bottom 10 nodes. We can see that the virtual money of the top 10 nodes increases quickly. Meanwhile, the virtual money of the bottom 10 nodes are becoming exhausted. At the \( 60^{th} \) day, the mean value of bottom 10 nodes have achieved 0. It means these poverty nodes have no virtual money to pay and also, they have been isolated by the network. Furthermore, the number of poverty nodes is kept growing. In such case, some of these nodes have higher probability to change into malicious nodes that threaten the social DTNs. In Figure 5, since we adopt the taxation strategy for the network, we can see that the income payoff of influential nodes is controlled effectively. Toward the poor nodes, because the virtual bank affords them necessary virtual money to guarantee the basic requirement of packet forwarding, these poor nodes would never be isolated by the network. In such case, these lower income payoff nodes have no desire to change to the malicious. From Figures 4 and 5, we can conclude that by using the Gini coefficient and taxation strategy, we avoid the internal threats which are caused by the social selfish behavior.

VI. CONCLUSION AND FUTURE WORKS

In this paper, we study the impact of individual and social selfish behaviors in DTNs. Toward the individual selfishness, we use the virtual bank and money to stimulate the nodes to cooperate with each other. Toward the social selfishness, due to the existing incentive mechanism is hard to solve it, we analyze the influence of social selfishness for DTNs. Based on the analysis, we conclude that the incentive mechanism of individual selfishness leads the internal threats in DTNs. The main reason of internal threats is that some nodes have less social relations and difficult to participate in the forwarding process. When these nodes cannot afford the forwarding cost, they will be isolated by the network and become malicious node. To avoid the internal threats, we measure the social wealth distribution of the DTNs by using Gini coefficient and design the taxation strategy to re-distribute the social wealth. Furthermore, we introduce our forwarding strategy based on the social relations of nodes.

In this paper, we think the nodes are rational and selfish in social selfish DTNs. We also assume the nodes are honest. That means although the nodes are selfish, they do not deceive others. However, in some real application scenarios, some nodes will deceive others to get increase their own payoff. In our future works, we will consider the cheating behavior by combining the social selfish behavior in DTNs.

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