WIM: A Wage-based Incentive Mechanism for Reinforcing Truthful Feedbacks in Reputation Systems

Huanyu Zhao and Xin Yang
Department of Computer Science
Oklahoma State University, Stillwater, OK 74078, USA
Email: {huanyu, xiny}@cs.okstate.edu

Xiaolin Li
Department of Electrical and Computer Engineering
University of Florida, Gainesville, FL 32611, USA
Email: li@ece.ufl.edu

Abstract—The success of current trust and reputation systems is on the premise that truthful feedbacks are obtained. However, without appropriate mechanisms, silent and lying strategies usually yield higher payoffs for peers than truthful feedback strategies. Thus, to ensure trustworthiness, incentive mechanisms are critically needed for a reputation system to encourage rational peers to provide truthful feedbacks. In this paper, we model the feedback reporting process in reputation system as a reporting game. We propose a Wage-based Incentive Mechanism (WIM) for enforcing truthful report in self-interested P2P networks. We design, implement, and analyze incentive mechanisms and players’ strategies. The extensive simulation results demonstrate that the proposed incentive mechanisms reinforce truthful feedbacks and achieve optimal welfare.

I. INTRODUCTION

Precious research results have shown that users tend to free ride and/or defect [1]. Many users may choose to consume the P2P systems resources without providing any of their own resources for the use of others. To ensure the service quality and handle the trust issues of these services in open and decentralized environments, trust and reputation scheme has been proposed to establish and manage trust relationships among peers. Reputation systems are natural vulnerable to dishonest and strategic feedbacks. In distributed P2P environment, there is no centralized administration to monitor the transactions status. Feedbacks are obtained by peer reporting. Most reputation schemes are established based on the assumption that users are willing to provide reputation feedbacks voluntarily and truthfully. However, in practice, reporting nodes are selfish instead of altruistic. Peers tend to employ silent and/or lying strategies that usually yield higher benefit than the honest feedback strategy. Peers have no natural incentive to provide truthful ratings, but act selfishly to maximize their own utility. The selfish peers may provide unjustified positive feedbacks for their friends. And they may submit dishonest feedbacks for their competitors. Selfish peers may also discredit others who have complained about them by providing negative feedbacks. For a reputation system, it is critical to ensure the scheme has the right incentives for selfish peers to provide truthful feedbacks. Lack of cooperative truthful report is one critical problem that confronts current trust and reputation systems.

This paper focuses on the specific incentive problem of reinforcing truthful feedbacks in P2P file sharing reputation systems. Respecting the rationality of P2P network users, we aims to make reputation systems incentive compatible. Our goal is to design a proper incentive mechanisms to prompt rational peers to offer truthful feedbacks while pursuing their own utility. To achieve this goal, we model the feedback reporting process as a reporting game. We analyze the game, and design a Wage-based Incentive Mechanism (WIM) to reinforce truthful feedbacks. A set of incentive compatibility constraint rules including participation constraint and self-selection constraints are formulated. Numerical results are presented and interpreted.

II. RELATED WORK

Trust and reputation systems have been extensively studied recently [2], [3], [4], [5]. To encourage truthful feedbacks, Jurca proposed to compare the two reports from the transacted seller and the buyer [6] and compare the reports with previous trusted reports [7] to determine the trustworthiness of the report. In decentralized environment, Jurca et al. proposed a currency-based payment scheme that encourages peers to provide truthful ratings[8]. In their paper, the agents only pay for the reputation feedback if and only if the feedback matches the next feedback submitted for the same target peer from another reporter. Michal Feldman and his colleague proposed an incentive approach based on game theory [9]. They model the problem using the prisoners dilemma. They propose a distributed reciprocative decision function as the incentives techniques. Papaioannou presented a truthful feedbacks incentive scheme for exchanging services in a P2P reputation system [10]. In their paper, both transacted peers are required to provide feedbacks on the mutual transaction’s performance. If the two feedbacks are not consistent which indicates that at least one of them is lying, both transacting nodes are punished. In their paper, a credibility mechanism is used to determine each peer’s punishment severity.

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III. INCENTIVE MECHANISM DESIGN

A. Problem Formulation

![Figure 1: The Truthful Feedback Problem for Non-Verifiable Information. For the querist Q, the transaction type is "hidden knowledge". Q issues a query to R to reveal the real transaction type. The feedback from R is non-verifiable information for Q.]

We assume a homogeneous file sharing P2P system without any centralized infrastructure. No peers are pre-trusted. A feedback based reputation system exists in such an environment. We represent the file download/sharing interactions as transactions. As shown in Figure 1, the reporter R knows the type ("successful" or "failed") after he finishes the file download transaction. For the querist Q, the transaction type is "hidden knowledge". Q issues a query to R to reveal the real transaction type. We assume most of the peers are strategic in the system. Peers behave rationally to maximize their own welfare. Without appropriate incentives, reporters may not choose to report truth. In addition, the feedback from a reporter R is usually not verifiable. It is hard for querist Q to verify whether reporter R is telling the truth. In this case, the objective verification is extremely hard if not impossible. This is the non-verifiable feedback problem in reputation systems.

The reputation system's basic concern is to obtain the truthful feedback. To achieve this goal, inspired by the mechanism design paradigm in a hidden knowledge setting [11], we model the feedback reporting process as a reporting game. We design a wage-based incentive mechanism and provide numerical solutions to obtain the minimum wage required to reinforce the truthful strategies. Under our mechanism, querists are not required to estimate/know truthfulness of feedbacks when paying wage. The wage paid to reporters only depends on the feedback regardless of truthfulness. Truthful revelation will be a dominant strategy for all reporters.

B. The Game Design

We define the notations as shown in Table I. We assume the output q, the transmission cost c, the utility \( U_Q \) and \( U_R \) can be evaluated/expressed by a currency/credit system. We model the feedback reporting process as a reporting game as shown below. In our game, the real transaction type \( T \) could be "successful" or "failed". The querist sets up game rules, and it hopes to employ an honest reporting node who always chooses feedback message \( m = T \). Each agent has the right to choose to play the game or not enter the game. If an agent joins the game as a reporter, it has to obey the game rules. A reporter reports the transaction type. The querist then assigns report wages to complete one reporting cycle.

![Table I: Notations]

- **Players**
  - The querist Q and the reporter R

- **The Game Procedure**
  - The querist offers the reporter a wage contract \( w(q,m) \) (\( q \) is output and \( m \) is the report message sending by the reporter). The reporter is paid \( w_s \) if its report \( m = \text{successful} \), \( w_f \) if its report \( m = \text{failed} \).
  - The reporter accepts or rejects the querist’s offer.
  - The transaction state \( T = \text{successful} \) with probability \( P \) and \( T = \text{failed} \) with probability \( 1-P \). The reporter observes the type of the transaction, but the querist does not.
  - If the reporter accepted the contract, it exerts effort \( c^2 (c = q/\alpha_s) \) to send report message if \( T = \text{successful} \), \( c = q/\alpha_f \) to send report message if \( T = \text{failed} \). The effort is unobserved by the querist.
  - Querist’s output is \( q \) for message \( m = \text{successful} \) and \( q_f \) for message \( m = \text{failed} \). And the wage is paid.

- **Utility**
  - If reporter rejects the contract, \( U_R = 0 \) and \( U_Q = 0 \)
  - If reporter accepts the contract, \( U_R = w - c^2 \) and \( U_Q = q - w \)

C. Contract Solutions

We present solutions on how to construct an optimal contract for a querist to retrieve truthful information. The contract is a set of rules that querist designs and reporter accepts in order to convey truthful information from the reporter to the querist. Considering the querist, its utility function equals to its output subtracts the wage paid to reporter in both states, \( U_Q = \left[ P(q_s - w_s) + (1-P)(q_f - w_f) \right] \) (1)

The querist aims to maximize its own utility,

\[
\text{Maximize} \ (U_Q)
\]

The contract must satisfy one participation constraint so that the reporter will accept the offer. For the reporter, the participation constraint is if it tells the truth, its earnings (utility) must be greater than 0. Or the reporters will not have motivation to join the game,

\[
P \left[ w_s - \left( \frac{q_s}{\alpha_s} \right)^2 \right] + (1-P) \left[ w_f - \left( \frac{q_f}{\alpha_f} \right)^2 \right] \geq 0 \quad (3)
\]

To maximize its own utility, the querist wants to offer the reporter as little wage as possible. So the participation constraint in Equation (3) is lower-bounded to 0,

\[
P \left[ w_s - \left( \frac{q_s}{\alpha_s} \right)^2 \right] + (1-P) \left[ w_f - \left( \frac{q_f}{\alpha_f} \right)^2 \right] = 0 \quad (4)
\]
In the game, the reporter is paid under one of two options, $w_s$ if it reports $m = \text{successful}$ and $w_f$ if it reports $m = \text{failed}$. To ensure the reporter telling the truth, reporting the false type for a transaction must result in a low payoff. Since the querist cannot verify the message, the contracts itself must induce reporter self-select truth message to report. In this game, the two self-selection constraints are that if the transaction type is "successful", the report’s utility sending $m = \text{successful}$ must be larger than the utility sending $m = \text{failed}$ message.

$$U_R(m = s | T = s) = w_s - \left( \frac{q_s}{\alpha_s} \right)^2 \geq 0$$

And if the transaction type is "failed", the report’s utility sending $m = \text{failed}$ must be larger than the utility sending $m = \text{successful}$ message.

$$U_R(m = f | T = f) = w_f - \left( \frac{q_f}{\alpha_f} \right)^2 \geq 0$$

In reputation system, we care more for "failed" transaction than "successful" transaction. In a system where we do not care for the report truthfulness for the "successful" transaction, the querist is not willing to increase the wage any more than necessary, so the "successful" state’s self-selection constraint in Equation (5) will be exactly satisfied,

$$w_s - \left( \frac{q_s}{\alpha_s} \right)^2 = w_f - \left( \frac{q_f}{\alpha_f} \right)^2$$

Solving Equation (4) and Equation (7) yields,

$$w_s = (1 - P)q_f^2 \left( \frac{1}{\alpha_f^2} - \frac{1}{\alpha_s^2} \right) + \frac{q_f^2}{\alpha_s^2}$$

$$w_f = \frac{Pq_f^2}{\alpha_f^2} + \frac{(1 - P)q_f^2}{\alpha_f^2}$$

Return to the querist utility maximization problem, substituting $w_f$ and $w_s$, we rewrite Equation (1) as,

$$U_Q = P \left[ q_s - (1 - P)q_f^2 \left( \frac{1}{\alpha_f^2} - \frac{1}{\alpha_s^2} \right) - \frac{q_f^2}{\alpha_s^2} \right]$$

$$+ (1 - P) \left[ q_f - \frac{Pq_f^2}{\alpha_f^2} - \frac{(1 - P)q_f^2}{\alpha_f^2} \right]$$

To get the maximum utility, the first-order conditions are,

$$\frac{\partial U_Q}{\partial q_s} = P \left( 1 - 2q_s \alpha_s^2 \right) = 0, \quad \frac{\partial U_Q}{\partial q_f} = 1 - 2q_f \alpha_f^2 = 0$$

Solving them yields,

$$q_s = \frac{\alpha_s^2}{2}, \quad q_f = \frac{\alpha_f^2}{2}$$

The wage combination reinforcing the truthful reporting is,

$$w_s = \frac{(1 - P)\alpha_s^2}{4\alpha_s^2} - \frac{\alpha_f^2}{\alpha_f^2}$$

$$w_f = \frac{P\alpha_f^4}{4\alpha_f^2}$$

The optimal wage is decided by environment parameters $\alpha_s$, $\alpha_f$ and $P$. We can also obtain querist’s and reporter’s utility,

$$U_Q = \frac{P\alpha_s^2 - \alpha_f^2 + \alpha_f^2}{4}, \quad U_R = 0$$

The reporter does not any earn information rents because of the single participation constraint is lower-bounded to 0 in Equation (4). The querist pays the reporter as little as it can be to achieve its own maximum utility.

**D. Analysis and Discussion**

In real world application, the environment parameters $\alpha_s, \alpha_f$ are determined by the report transmitting effort and output. And probability distribution $P$ is determined by transaction’s own essential characteristic. To ease the understanding of WIM solution and its features, we fix $\alpha_s = 3, \alpha_f = 1$ and $P = 0.5$. We get $q_f = 0.5$ and $q_s = 4.5$ from Equation (12), $w_s \approx 2.36$ and $w_f \approx 0.14$ from Equation (13). (14).

Recall the payoff formula presented in the reporting game. If a reporter accepts the contract, $U_R = w - c^2$ and $U_Q = q - w$, the reporter’s payoff can be calculated. The reporter’s payoff matrix is shown in Figure 2(a). There is no penalty for lying from a querist because querist never verifies the information and cannot determine lying or not. The reporter gets $w_s$ for a “successful” feedback and $w_f$ for a “failed” feedback regardless of the real transaction result. The reporter gets low payoff because that the effort $c$ to tell false is high. Another observation is when the transaction state is “successful”. There are two equilibriums that one of them implies lying. This is because the environment setting, in the reputation system, the querist cares failed transactions much more than successful transactions. Querist only has to ensure the lying strategies do not yield reporter higher payoffs than the truthful reporting strategy. Querist does not intend to pay any extra wage. So querist reduces his paid wage for undesired information. The analysis shows that WIM scheme eliminates the undesired equilibriums $\{m = \text{successful}, T = \text{failed}\}$ in reporting game. However, in a situation where successful transaction is important information, the non-truthful equilibrium $\{m = \text{failed}, T = \text{successful}\}$ becomes even more problematic. To eliminate this non-truthful equilibrium, Equation (5) should be changed to “>” rather than “≥”, leading to a slightly increased wage.

Similarly, querist’s payoff matrix can be calculated and shown in Figure 2(b). The querist never verifies the incoming information. What he has to do is to assign $w_s$ for “successful” feedback and $w_f$ for “failed” feedback regardless of the real transaction state.
IV. EXPERIMENTAL EVALUATION

A. Simulation Setup

A P2P network for file sharing is simulated. The network is configured of 1000 nodes with an average node lifetime of 200 hours. All nodes are independently and identically distributed in the system. To evaluate the performance in dynamic environment, new generated nodes are continuously joining the network according to a poisson distribution (arrival rate $\lambda = 10$ per iteration cycle), and nodes die and nodes leave are also randomly happened. The node population size stays constant which is 1000 in our experiment. The storage space of each node is 1MB. We assume there are small files stored per nodes. The unit time is 1 hour which represents one feedback iterations round. Each peer was assigned an initial currency/credit following a normal distribution with mean $\mu_c = 50$ and variance $\sigma_c^2 = 10$. The file download transactions occur in each iteration, with the occurrence rate 10% of the total population. In each iteration, two nodes are randomly paired to start small file download transaction once. Mutual transactions are reported by reporters. A third node acts as the querist and queries the transaction type.

We use the environment parameter setting in Section III-D as the “basic wage scheme” where $\alpha_s = 3$, $\alpha_f = 1$ and $P = 50\%$. Accordingly, the outputs are $q_f = 0.5$, $q_s = 4.5$, and the wages are $w_s \approx 2.36$, $w_f \approx 0.14$. We assume the P2P system is a homogeneous system. All transactions consume the same cost to reporters and provide the same output to querists. We also propose the “enhanced wage scheme” in which we increase wage to $w_s \approx 2.5$ to eliminate $\{m = \text{failed}, T = \text{successful}\}$ equilibrium. In the enhanced wage scheme, $w_f$ stays the same as in the basic wage scheme.

All nodes are self-interested, and they can change their interaction strategies/behavior adaptively to maximize their own utility (credits in this experiment). A cooperative node indicates that a node provides truthful feedback, while a noncooperative node represents a node that gives dishonest report. However, To measure some unpredictable behavior in real-world application, we allow peers to randomly adopt some irrational reporting activities at a low probability 5%. At the start stage, there are a mix of 500 cooperative nodes and 500 noncooperative nodes.

B. Results and Analysis

We define the density of a strategy as the number of the nodes employing the strategy (cooperative/noncooperative) among all the nodes. The relation between strategies density and time in the basic wage scheme and enhanced wage scheme is shown in Figure 3. At the starting stage, there are 500 cooperative nodes and 500 noncooperative nodes. After a few iterations, the cooperative nodes dominate the population of the network in both the two schemes. For the basic wage scheme, the cooperative population is around three fourths which is less than in the enhanced wage scheme. This is because in the basic wage scheme, when the transaction state is “successful” there is no incentive for peers to report truth.

That is, in the “successful” status, the basic wage scheme has two equilibrium $\{m = \text{success}, T = \text{success}\}$ and $\{m = \text{failed}, T = \text{success}\}$, which results a portion of dishonest report. In the enhanced wage scheme, the cooperative nodes increase sharply for the reason that the enhanced wage eliminate the $\{m = \text{failed}, T = \text{success}\}$ equilibrium. Nodes receive higher payoff if they report truth in “success” state. The cooperative peers cannot achieve 100% because we allow peers to randomly adopt some irrational activities at a low probability 5%, which leads to some unpredictable reporting activities.

Figure 4(a) shows the querists’ and reporters’ average utility in basic wage and enhanced wage scheme. Querists’ average utility keeps increasing linearly. In enhanced wage scheme, querists’ utility increase faster than the basic scheme. This is because the enhanced wage eliminate $m = \text{failed}$ report at $T = \text{success}$ status, it leads to more output credits for querists. The reporters’ average utility keep decreasing which is a little different from the analytical results calculated by Formula (15) (the reporters’ average utility maintains at the same level) because we allow peers to randomly adopt some irrational behavior. The reporters’ average utility is higher in enhanced wage scheme than basic scheme for the reason querists provide reporters more wage in enhanced wage scheme. The querists achieve maximum utility while enforcing the truthful feedback when they enhance the wage as little as it can be above the boarding line. The average social utility which is the sum of the querists’ utility and reporters’ utility is shown by Figure 4(b). By enhancing the wage, we achieve higher social utility in enhanced wage scheme.

Dishonest feedback represents the feedback that is not consistent with the real transaction type. Fatal dishonest feedback is defined as $\{m = \text{success}, T = \text{failed}\}$ which can damage the reputation system because it hides a failed transaction. Dishonest feedback and fatal dishonest feedback rate in both schemes are shown in Figure 5(a) and Figure 5(b). In both schemes, $\{m = \text{success}, T = \text{failed}\}$ feedbacks are less than 5%. Note that, lots of the dishonest feedbacks are generated by nodes’ irrational behavior which are preset in simulation environment parameters. In the basic scheme, there is a large portion of $\{m = \text{failed}, T = \text{success}\}$
V. Conclusion

We have presented the game theory model and wage-based incentive mechanism to encourage truthful feedback in reputation systems. Our contributions in this work are multifold. (1) Assuming peers in reputation systems are self-interested, we model the feedback reporting problem to the reporting game. (2) We design a wage-based incentive mechanism for enforcing truthful report. Different from most existing schemes, our algorithm does not require the peers to verify the information truthfulness. The solution requires only localized wage payment scheme. (3) To gain better understanding of landscape in our scheme, initial characteristics of our scheme are investigated. (4) We design and conduct extensive simulation evaluation and the results demonstrate clearly that our scheme enforces the truthful report and renders lying costly. We believe that our scheme establishes a solid foundation to design incentive-compatible trust and reputation systems.

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