Trust and Cooperation in Peer-to-Peer Systems

Junjie Jiang, Haihuan Bai, Weinong Wang

Department of Computer Science and Engineering
Shanghai Jiaotong University, Shanghai 200030, P.R.China
{jjj, baihh, wnwang}@sjtu.edu.cn

Abstract. Most of the past studies on peer-to-peer systems have emphasized routing and lookup. The selfishness of users, which brings on the free riding problem, has not attracted sufficient attention from researchers. In this paper, we introduce a decentralized reputation-based trust model first, in which trust relationships could be built based on the reputation of peers. Subsequently, we use the iterated prisoner's dilemma to model the interactions in peer-to-peer systems and propose a simple incentive mechanism. By simulations, it's shown that the stable cooperation can emerge after limited rounds of interaction between peers by using the incentive mechanism.

1 Introduction

During the recent few years, peer-to-peer computing has caught much attention. Informally, a peer-to-peer system is comprised of many peer nodes, which have equal roles and responsibilities. They differ from traditional distributed computing systems in that no central authority controls or manages the various components; instead, all the peer nodes form a dynamically changing and self-organizing network.

Much of the past work in peer-to-peer systems assumes that all these peers will follow prescribed protocol without any deviation and they will cooperate voluntarily in order to perform some task or share their resources by direct exchanges. However, it's not always true in real case. This assumption is based on user's voluntary altruism and ignores the user's ability to modify the behavior of an algorithm for self-interested reasons. In fact, the free riding problem has become a severe obstacle of the deployed peer-to-peer applications. A recent study of Gnutella has found that an overwhelming proportion of its users take advantage of the network without contributing anything to it [1]. As a growing number of users become free riders, the system starts to lose its peer-to-peer spirit, and begins to retrogress to a traditional client-server system. Therefore, an appropriate incentive mechanism is necessary, which motivates peers to contribute their resources to the system.

The rest of this paper is organized as follows. In section 2, a decentralized reputation-based trust model is introduced. Incentive patterns are also discussed in this section. Section 3 uses the iterated prisoner's dilemma to model the interactions in peer-to-peer systems and proposes a simple incentive mechanism. In section 4, results

from simulation experiments are provided. Section 5 shortly discusses related work and section 6 concludes this paper.

2 Trust Model and Incentives Patterns

There is no central authority in a pure peer-to-peer system. Obviously a centralized trust model is not suitable for peer-to-peer systems. The usual decentralized alternate to central CA is the web-of-trust model. But web-of-trust is susceptible to the treachery of even one trusted peer and it has primarily been used for privacy purposes. In this section, we will introduce a decentralized reputation-based trust model.

2.1 A Reputation-Based Trust Model

Trust is an essential element in peer-to-peer systems. In a peer-to-peer system, each peer faces complicated trust relationships with others. It's necessary to help peers build such trust relationships. This should appeal to an appropriate trust model.

Trust is a basic feature of social situations that require cooperation and interdependence. However, there's still lack of consensus on the definition of trust in the literature. In this paper, we use the following definition for trust:

- Trust is the belief that the counterpart will behave as the expectations. It is a variable value associated with the peer but yet it is subject to the peer's behavior and applies only within a specific context at a given time.

According to the definition above, trust is subjective, mutable and non-quantifiable. But in order to characterize different trust levels, we can represent the trust as a real number within a specific range. Abdul-Rahman and Hailes [2] have proposed that the trust concept can be divided into direct and recommender trust. We divide the trust into direct and indirect trust. Direct trust can be derived from the experiences of direct interactions between peers while indirect trust can be derived from others' recommendations. Moreover there is a special type of direct trust called as recommender trust, which is the trust that one peer has in its recommenders (who provide recommendations to it). We subject recommender trust to direct trust and specifically here, the direct interaction is request and recommendation. But for the clarity of notions, we still distinguish the recommender trust from direct trust. As shown in Figure 1, there are three types of trust relationships distinguished.

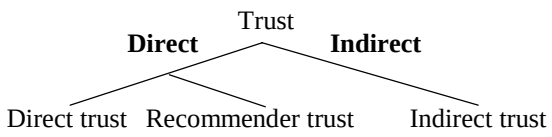

Fig. 1. Three types of trust relationships

Since a peer-to-peer system always involves a large number of peers (up to millions of peers), there is little chance of direct interaction between any pair of peers. As to most of the peers, especially a newcomer, there are too many strange peers. They cannot derive the direct trust towards these strangers based on their direct interaction experiences. So they have to appeal to the recommendations from their familiar peers, namely the recommenders of them. By requesting these recommenders, the peer can gather recommendations about a specified peer and infer the indirect trust value. Generally, the recommendations about a peer are based on its reputation. The definition of reputation is shown as follow:

- The reputation of a peer is an expectation of its behavior based on other peers' observations or the collective information about the peer's past behavior within a specific context at a given time.

In fact, each peer is involved in a trust net. A trust net encodes how peers estimate the quality of other peers they have not interacted with before. Trust net is a logical network that interconnects the requestor peer and the objective peer, where the intermediate nodes are those recommenders. All the recommenders of a peer constitute the recommenders' group of the peer. The trust net, as well as the recommenders' group, is dynamic and context-specific. An example of trust net is shown in Figure 2.

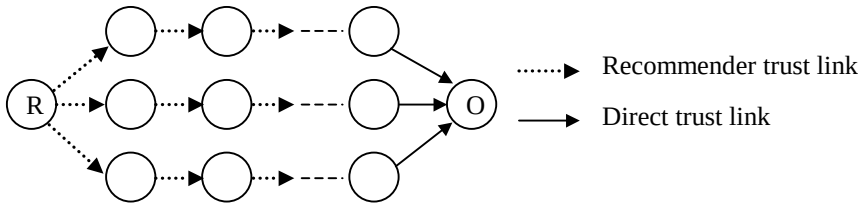

Fig. 2. An example of trust net

When a requestor peer wants to evaluate the trustworthiness of a objective peer, it may request the members of its recommenders' group. These recommenders will return their direct trust value in the objective peer if they have, otherwise request their own recommenders on the trustworthiness of the objective peer. The rest may be deduced by analogy. Finally, all these recommendations will be passed to the requestor peer. Many computational models [3] [4] have been proposed for translation from recommendations to trust value.

In the trust net, a path from requestor peer to objective peer is referred as a recommendation chain. A recommendation chain is always composed of two types of links, i.e. direct trust links and recommender trust links. The procedure of recommendation is just the propagation of the objective peer's reputation along the recommendation chain. The inference of trust values may recur to the theory of Dempster-Shafer [5]. There are two basic operations for the inference in this theory. The first is trust decay operation along a recommendation chain. The second is independent similar trust reinforcement among multiple recommendation chains. We can also choose other

approaches for the inference of trust value such as the cross product and dot product operations [6].

Actually, the accuracy of the acquired reputation information relies upon not only the honesty of recommenders, but also the similarity of the preference between the requestor peer and recommender peers. After each recommendation evaluation, the peer will update its recommender trust according to the variance between the recommendations from these recommenders and the final trustworthiness of the objective peer. If the recommender trust in a certain recommender is under a threshold value, the recommender will be eliminated from the recommenders' group. Also there some peers may be added into the recommenders' group at any moment. Through a period of in and out, most members in recommenders' group will have somewhat similar preference with the peer.

Perhaps some peers can derive neither direct nor indirect trust value towards a given peer. They may use the default trust value, which reveals their default attitude (e.g. altruistic, rational or free riding) to the society of peers.

2.2 Incentive Patterns

Peers can benefit from free riding on the resources contributed by others. Thus, incentives for sharing resources are indispensable to combatting free riding on peer-to-peer systems.

There are two forms of incentives that have been considered in the past [7]: (1) Trust based patterns, in which peer will be rewarded good appraisement (good reputation) if it cooperates, otherwise, it will be criticized. Good reputation will help the peer obtain better services in the future. (2) Trade based patterns, in which rewards are explicit, and before each interaction, the resource consumer should pay for the service in advance. Alternatively, the pay may occur after the service by the negotiation with the resource provider. There are also different labels for incentives [8]: (1) monetary payments (one pays to consume resources and is paid to contribute resources), and (2) differential service (peers that contribute more will get better quality of service). They correspond to the trade based and trust based incentive patterns respectively. The two forms of incentives may be applied in different application situations. Particularly, three incentive schemes (token-exchange, peer-approved and service-quality) are referred in [9].

3 Strategy for Cooperation

We can outline the interrelationship among peer's reputation, and trust and cooperation between peers (See Figure 3). Improvement in reputation will make peers more trustworthy. Mutual trust between peers and appropriate incentives will bring out cooperation. Also more cooperation will get more rewards in reputation.

The iterated prisoner's dilemma is an elegant model for the emergence of cooperation in a multi-agent system. This section uses the iterated prisoner's dilemma to model the interactions between peers.

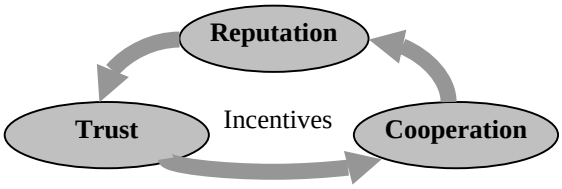

Fig. 3. Interrelationship among reputation, trust and cooperation

3.1 Iterated Prisoner's Dilemma

The prisoner's dilemma is a classic problem of conflict and cooperation. The dilemma stands on the fact that individual interests differ from collective ones. The prisoner's dilemma is a two-person non-zero-sum, non-cooperative and simultaneous game. In the simplest form, two players are both faced with a decision – either cooperate (C) or defect (D). The payoff depends on the decisions made by the two players and each receives payoff according to a payoff matrix. Table 1 shows the scores of each player in each combination of strategies.

Table 1. Payoff matrix in the prisoner's dilemma

Player B

Player A		**Cooperate**	**Defect**
	Cooperate	R / R	S / T
	Defect	T / S	P / P

R = 3
T = 5
P = 1
S = 0

If both the players cooperate, they receive a reward ***R***. If both defect, they receive a punishment ***P***. However, there is a temptation ***T*** to defect for a player because the temptation is more beneficial than reward when the other player cooperates. Simultaneously, the sucker receives a more severe punishment ***S***. The following inequality should be respected:

$$S < P < R < T$$

The one-shot prisoner's dilemma is not very interesting since rational players will always select defection. A variation of the prisoner's dilemma is known as the iterated prisoner's dilemma, in which more complex strategies become possible. The iterated prisoner's dilemma is about how the members of a social group either win or lose through repeated interactions with other members of the group and each player's payoff is the sum of the score in each past round. In the iterated prisoner's dilemma, a history of prior behavior and the opportunity for payback in the future may influence the decision that each player makes. It has been shown that cooperation can emerge in

the iterated prisoner's dilemma. In addition, the payoff matrix in the iterated prisoner's dilemma should meet the following inequality:

$$T + S < 2R$$

3.2 Incentives and Strategies

We use the iterated prisoner's dilemma to model the interactions in peer-to-peer systems. Each peer is a player and an individual interaction is modeled as a single round in the iterated prisoner's dilemma.

The iterated prisoner's dilemma format tends to offer a long-term incentive for cooperation, even though there is a short-term incentive for defection. The reputation of one player will influence the strategy choice of its opponent and thus its payoff. So each player must care the effect on its reputation at each move.

There are many well-known strategies, such as tit-for-tat, studied in the iterated prisoner's dilemma. ***Credit Score*** is a strategy in the iterated prisoner's dilemma, in which a player cooperates on the first move, and thereafter plays opponent's most used strategy (if equal then cooperates).

Incentive schemes for peer-to-peer systems may be derived from these strategies. For a trust based incentive scheme, a reputation system is always used to maintain the reputation information of peers [9]. Here we assume the existence of such a reputation system. Such reputation just records the history of prior behaviors of peers. Based on such information of opponents, peers make decisions according to their own strategy.

Here, we propose a trust based incentive scheme named as ***Credit Score***. In ***Credit Score***, a peer cooperates at its first interaction. Hereafter it will evaluate its counterpart before each interaction. The peer, if it cooperated no less than defected before, is taken as a popular peer, otherwise an annoying peer. A ***Credit Score*** peer will cooperate while facing such a popular peer, otherwise defect. We present this incentive scheme just to illustrate that we can derive some effective incentive schemes from strategies in the iterated prisoner's dilemma.

4 Simulations and Results

The purpose of this section is to investigate the effectiveness of the ***Credit Score*** incentive scheme under simulations. Our simulator implements the interaction model described in Section 3, and each peer is implemented as an agent. The experiments emulate the natural selection process. At the end of each generation, the total score for the population is tallied. Strategies that have relatively higher payoff become more widespread in the population, and those that have relatively lower payoff become less common. The evolution continues until there are no changes in population between two generations.

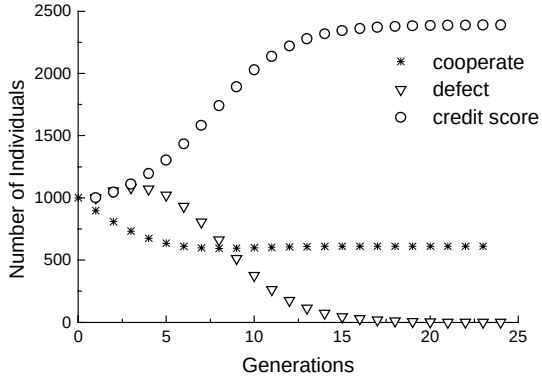

Fig. 4. An example of the evolution of strategy populations over time

Figure 4 depicts the evolution of peers to higher score strategies over time. The original population consists of 1000 unconditional cooperators, 1000 unconditional defectors and 1000 peers who use ***Credit Score*** scheme. After several generations, the population eventually stabilizes. By the end of the simulation, the number of unconditional defectors decreases to zero since the unconditional defectors can only achieve a very low fitness in the society and are naturally eliminated from the population generation by generation. The result shows that the ***Credit Score*** scheme is effective. We also conduct another simulation experiment, in which the original population consists of only 1500 unconditional cooperators and 1500 unconditional defectors. It's shown that all the peers become unconditional defectors by the end of the simulation. This indicates that the peer-to-peer system collapses.

5 Related Work

The incentive problem is indispensable for wide deployment of peer-to-peer systems. Some work has involved in this problem. Buragohain et al [10] study the interaction of strategic and rational peers and propose a differential service-based incentive scheme to improve the system's performance. They also use the Cournot duoploy like model to analyze the utility model. Golle et al [8] construct a formal game theoretic model of peer-to-peer file sharing system and analyze equilibria of user strategies under micro-payment mechanisms. Wang et al [11] model the peer-to-peer system as a Cournot Oligopoly game with dynamic payoff function and propose a control-theoretic solution to the problem. Kevin Lai et al [12] use evolutionary prisoner's dilemma to model the cooperation in peer-to-peer systems and they outline the design space of incentive strategies. We use iterated prisoner's dilemma to model the interactions in peer-to-peer systems and emphasize that the reputation of peers will influence their future payoff.

6 Conclusion

This paper has introduced a reputation based trust model for evaluating the trustworthiness of a peer. In the model, the reputation of peers is derived based on the history of their behaviors. We use the iterated prisoner's dilemma to model the interactions in peer-to-peer systems and propose a trust based incentive scheme named as ***Credit Score***. By simulations, we found that we can derive some effective incentive schemes from strategies in the iterated prisoner's dilemma.

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