Designing an Incentive-Based Framework for Overlay Routing

Gene Moo Lee, Taehwan Choi, and Yin Zhang
Department of Computer Sciences,
The University of Texas at Austin
{gene, ctlight, yzhang}@cs.utexas.edu

Abstract

Overlay routing becomes popular as an incremental mechanism to improve the Internet routing. So far, overlay nodes are always assumed to be cooperated to each other. In this paper, we analyze the overlay routing in a new viewpoint, in which the overlay nodes act independently to maximize their own payoff. We use game theoretic approach to analyze the transit traffic forwarding, and realize that overlay nodes are not likely to cooperate each other in our new scenario.

In order to stimulate the independent overlay nodes to cooperate each other, we design and propose an incentive-based framework. We introduce three possible systems and evaluate them analytically. Among the candidates, we use simulation to verify the feasibility of our proposed framework *generalized punish-and-reward system*. The performance gets closer to social optimum as we increase the number of punishments. In addition, the system shows tolerance against impatient players.

1 Introduction

Overlay networks have been succussful for many applications such as content distribution networks, peer-to-peer file sharing, ad-hoc networks, distributed look-up services, application-layer multicast overlays, and virtual private networks. Especially, it has been shown by [1] and [2] that overlay routing can significantly improve the sub-optimality of the Internet routing. Most overlay systems assume that individual nodes will cooperate with each other to achieve the goal of the whole system.

However, as the overlay network becomes more popular, we argue that the system will get decentralized and it will consist of independent overlay nodes. The node will choose the action with its own decision. We assume that an overlay node will selectively forward traffic from other nodes in order to maximize its benefit and to minimize the cost. The benefit a node can achieve is better routes with lower latency and lower loss rate. In the meantime, the node will consume some resource when forwarding transit traffic on behalf of other nodes. The cost includes packet processing time, memory consumption, and network bandwidth.

We analyze the behavior of the overlay nodes by formalizing the transit traffic forwarding as a non-cooperative game [3]. Since the nodes in overlay routing are network routers, we assume that the identity of the nodes are well-known to each other and that every pairs of nodes will repeat the game infinitely. Our analysis shows that players are not likely to cooperate if there is no regulation mechanism.

In this paper, we introduce incentive-based frameworks [3], which are designed to stimulate the players to cooperate in overlay routing. We analyze three trigger strategies for the repeated game: grim-trigger, tit-for-tat, punish-and-reward. We give sufficient conditions, in which the independent nodes follow the rule of the systems. In addition, we generalize the punish-and-reward system to induce more cooperations of the players.

Among the possible strategies, we evaluate the generalized punish-and-reward system with simulation. The system stimulated significant amount of cooperations with limited number of punishments. The performance gets closer to the social optimum as we have more cooperations. In addition, the framework shows good tolerance against impatient players.

To the best of our knowledge, there is no general framework to stimulate cooperations in overlay routing networks. Considering an increasing role of overlay networks, proposed mechanism will merit general purpose systems of overlay networks.

The paper is organized as follows. First, we assume our model and define the problem in Section 2. Then we use game-theoretic approach to analyze the behavior of the overlay nodes in Section 3. In Section 4, we propose our framework to make incentives to cooperate in the overlay routing. Section 5 evaluates the proposed method using simulation. In Section 6, we discuss related research works. We conclude the paper and describe future direction in Section 7.

2 Our Incentive Model

In this section, we introduce requirements and assumptions, and formalize the model of transit traffic forwarding problem in overlay routing. Then we give the problem definitions of this paper.

2.1 Requirements and Assumptions

1. Quantifying benefits and costs: Overlay nodes can get better routing paths with the help of other nodes. The benefit we can achieve includes lower latency and lower loss rate. We may precompute these benefit values using network coordinate systems [4]. We assume that all the players know the benefit for each opponent. In the meantime, overlay nodes spend some resource to forward traffic from their opponents. The cost includes CPU time, memory consumption, and network bandwidth. Based on the current demand, each overlay node calculates the cost that will occur to the opponent and announces this information to the opponent. Since we are dealing with different kinds of metric, we need to convert them into dimensionless parameters.

2. Strategic and rational overlay nodes: The participants are strategic in the sense that they can choose their own actions whatever they want, and that these actions lead to different outcomes. A node can take action to forward or to drop the traffic from a given oppponent node. In addition, overlay nodes are rational to maximize their own utility value. Since overlay nodes in our context are routers, we exclude the case where some players are malicious.

3. Overlay nodes are trustworthy: We assume that each overlay node will truthfully report the cost that will occur to forward the transit traffic and the benefit the node can get from the opponent. It will be an interesting problem to think about the incentive of players to truthfully report them. However, it is not a focus of this paper. Another assumption is that if an overlay node agrees to relay other's traffic, it will actually put its best effort to deliver the traffic to the destination.

4. Identities of nodes: The overlay nodes are routers and the identities

Player 2

Player 1	Relay	Not Relay
Relay	$b_{1,2}-c_{1,2}/b_{2,1}-c_{2,1}$	$-c_{1,2}/b_{2,1}$
Not Relay	$b_{1,2}/-c_{2,1}$	0/0

Figure 1: Traffic relaying game in overlay routing is equivalent to Prisoner's Dilemma

are known to each other. Consequently, the participants have long term relationship. However, in P2P system, the up-time of the clients are relatively short, which makes it difficult to regulate anonymous free riders.

2.2 Problem Definition

In this paper, we want to answer the following questions. *What will be the overall performance if overlay nodes are independent?* If the overlay nodes can be controlled by a central entity, we may achieve the social optimal performance. However, as the overlay nodes seek individual optimality, it is likely that the overall performance degrades (price of anarchy). In section 3, we will analyze the transit traffic forwarding as a non-cooperative game. Given the overlay network experiences performance degradation by the selfishness, then the next question is: *how can we design a mechanism to encourage overlay nodes to cooperate each other and to get closer to socially optimal performance?* In section 4, we propose our framework to solve this problem.

3 Traffic Relaying Game

We want to predict what will happen if the overlay nodes are independent players in this section. Since the action of each player will lead to the final outcome, we use game theory to analyze the overlay routing.

Since there is no standard consensus on the overlay network construction process, we describe the procedure we will use in this paper. (1) When a router joins the overlay, it receives the protocol of the overlay network. (2) With the current traffic demand, each node calculates the benefit it can achieve from other nodes. (3) Each node sends traffic relaying requests to the opponents with the cost information such as network bandwidth and traffic amount. (4) Based on the benefit and cost values, each pair of nodes play traffic forwarding game.

Figure 1 shows the transit traffic forwarding game in the overlay routing. We assume that both players simultaneously select their actions: to relay the opponent's traffic or not. If both players forward the traffic on behalf of each other, both get the benefit from each other and consume their resource for each other. If only one of the players relays the traffic, the cooperative player pays the cost without benefit and the other player receives the benefit without any cost.

Here we introduce some notations for our convenience. We assume that there are N players and $\frac{N(N-1)}{2}$ separate games among them. In the game between player i and player j, we denote the partial utility function of player i to be $u_{ij} = -c_{ij} + b_{ij}$, where c_{ij} is the cost player i should pay to relay player j's traffic and b_{ij} is the benefit player i can get from player j's help. Then total utility function of player i is $\sum_{i \neq j} u_{ij}$. We will use b and c without the subscripts if there is no confusion.

Let's consider the best action each player can take in this game. Assuming player 2 relays the traffic, player 1 gets better payoff B_1 by not relaying the traffic. With the assumption that player 2 does not help out, player 1 is still better off to refuse the duty. Similarly, player 2 will not cooperate with the same argument. Thus, $(NotRelay, NotRelay)$ is a *Nash equilibrium* of this game. The players are said to be at Nash equilibrium if no player can improve its utility by unilaterally changing its strategy. For the rest of the paper, we will use R for *Relay* and N for $NotRelay$ and $(NotRelay, NotRelay)$ will be denoted as (N, N).

With this argument, we can see that overlay nodes are unlikely to cooperate without some external control. Thus, we need some mechanism to give incentives to players to cooperate. Intuitive approach could be to record the history of other players' actions and maintain the reputation value of the opponent player.

We model the traffic forwarding in overlay routing as a repeated game because the overlay nodes are network routers and the interaction between nodes will be repeated. Since we do not expect the end of the interaction, we treat it as an infinitely-repeated game. This feature is different from the case of P2P system, where anonymous players have incentives to get the download and to leave the system without any contribution.

In the repeated game, overlay nodes play the game in figure 1 over and over. The utility value is simply the total sum of the utility the player gets in a one-shot game. Since the game is played infinitely, we have to differentiate between the utility achieved in the current time and the one in the future games. *Discount factor* ($0 \leq \delta \leq 1$) is the weight we put on the future utility. If $\delta = 0$, the player only considers the current payoff and ignores the future impact. If δ gets closer to 1, the player puts almost equal importance on the future payoff as the present value.

4 Incentive-Based Frameworks

In this section, we introduce possible frameworks, which are adopted from game theory [3]. They are designed to encourage cooperation in overlay routing. We itemize the requirements of the framework we want to achieve. Then we describe some candidate systems and evaluate them using mathematical analysis.

The followings are some requirements that the system should meet. (1) The system stimulates the independent players to cooperate each other. (2) The system is robust with the "impatient" players (i.e. lower δ value). (3) The outcome of the system is close to the social optimal performance.

Here are possible systems for our goal:

- Grim-Trigger: If both players cooperate in the past, they repeat the cooperation forever. However, if there is a player who defected, there will be no cooperation thereafter.
- Tit-for-Tat: In this system, each player repeat whatever the opponent played in the previous game. This follows the human analogy "an eye for an eye, a tooth for a tooth".
- Punish-and-Reward: We consider the notion of "forgiveness" in this system, whereas grim-trigger only includes punishing mechanism. A player in a bad reputation can restore its state by receiving the punishment.

4.1 Grim-Trigger System

In grim-trigger system, everyone enjoys the cooperation until there is one player who defects at some point. Figure 2 shows the state diagram of the

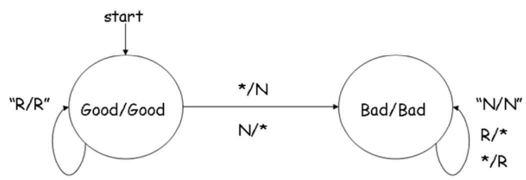

Figure 2: Grim-Trigger State Diagram

system. The quoted actions are what our rule requires the players to obey. Both players start with the good state as long as both of them relay the opponent's traffic. But if one of them refused to relay at some point, both of them go to bad state and stay there forever.

The grim-trigger is strong and extreme because there is no forgiveness. If one of the players refuse to cooperate, both players will not cooperate forever. Therefore, players will be really cautious to refuse the cooperation.

Since the overlay nodes are independent, they can choose whether to go along with the system or not, based on the expected payoffs. The following proposition gives a condition where players will follow the rule.

Proposition 1 *Grim-Trigger System induces the cooperation of the players as a subgame perfect Nash equilibrium if $\delta \geq c/b$.*

Proof: It is shown in [3] that it is enough to consider one time unilateral deviation to show it as a Nash equilibrium. For each state, we consider the utility payoff each player can have by obeying or deviating, assuming that both players will obey the rule thereafter.

Suppose players are in the good state. Then the rule is to play (R, R). If player 1 obeys the system (R, R), both players will stay in the good state. If player 1 deviates from the rule by (N, R), there will be no cooperation forever.

$$\begin{aligned} u_1(obey|GG) &= \sum_{i=0}^{\infty} (b-c)\delta^i = \frac{b-c}{1-\delta} \\ u_1(deviate|GG) &= b + \sum_{i=1}^{\infty} 0\delta^i = b \end{aligned}$$

Player 1 will obey the rule if $\delta \geq c/b$ in the good state. We can have a dual argument for player 2.

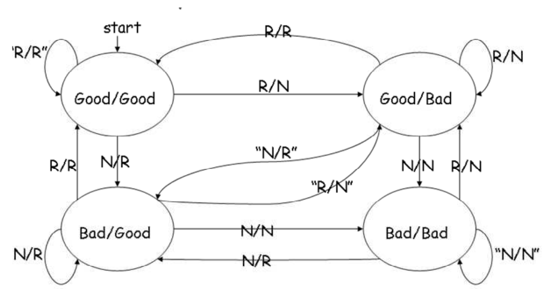

Figure 3: Tit-for-Tat State Diagram

Suppose players are in the bad state. Then the rule is to play (N, N). Regardless of player 1's actions, they will stay there forever.

$$u_1(obey|BB) = \sum_{i=0}^{\infty} 0\delta^i = 0$$

$$u_1(deviate|BB) = -c + \sum_{i=0}^{\infty} 0\delta^i = -c$$

Players are always better off to follow the system in the bad state.

Since both players start in the good state, grim-trigger system will make the cooperation if $\delta \geq c/b$. $\square$

Given the discount factor δ is fixed, the ratio of cost c and benefit b directly make impact on the system performance. If $c = 0$, then $c/b = 0$ and every player will cooperate to relay the traffic from the opponent. Otherwise, if $b = 0$, then $c/b = \infty$ and there is no δ satisfying the equation. All players do not have incentives to cooperate in this case. This is consistent with our intuition.

4.2 Tit-for-Tat System

Tit-for-tat system follows the human analogy "an eye for an eye, a tooth for a tooth". Every player will repeat whatever the opponent played in the previous round, as described in Figure 3. If both of them cooperate, they will enjoy the cooperation forever. However, if one of them deviates from the responsibility, the opponent will devtiate in the next round. In this system, pushnishment will result another punishment, which makes an infinite chain of "revenges".

Because of this chain, it is likely that the system becomes unstable. As proved in the following proposition, only a limited player will follow the rule, which shows that the system is not tolerant. An advantage is that it does not require explicit state maintenance because players do whatever they got.

Proposition 2 *Tit-for-Tat System induces the cooperation of the players as a subgame perfect Nash equilibrium if $\delta = c/b$.*

Proof: Suppose both players are in the good state. Then the rule is to play (R, R) in the next game. If player 1 obeys the system, both players will stay in the good state. If player 1 deviates from the rule by (N, R), there will be infinite chain of revenge.

$$\begin{aligned} u_1(obey|GG) &= \sum_{i=0}^{\infty} (b-c)\delta^i = \frac{b-c}{1-\delta} \\ u_1(deviate|GG) &= \sum_{i=0}^{\infty} (b-c\delta)\delta^{2i} = \frac{b-c\delta}{1-\delta^2} \end{aligned}$$

Player 1 will obey the rule if $\delta \geq c/b$ in the $(Good, Good)$ state. The same argument applies to player 2.

Suppose player 1 is in the good state but player 2 is in the bad state. Then the rule is to play (N, R) in the next round. Player 1 will stay in the revenge chain if it obeys the rule. If the player deviates and forgives the opponent player, then they will enjoy the cooperation thereafter.

$$\begin{aligned} u_1(obey|GB) &= \sum_{i=0}^{\infty} (b-c\delta)\delta^{2i} = \frac{b-c\delta}{1-\delta^2} \\ u_1(deviate|GB) &= \sum_{i=0}^{\infty} (b-c)\delta^i = \frac{b-c}{1-\delta} \end{aligned}$$

Player 1 will obey the rule if $\delta \leq c/b$ in the $(Good, Bad)$ state.

Now, let's look at the player 2's perspective. If player 2 obey the rule, then they stay in the revenge chain. Otherwise, both players go to bad state

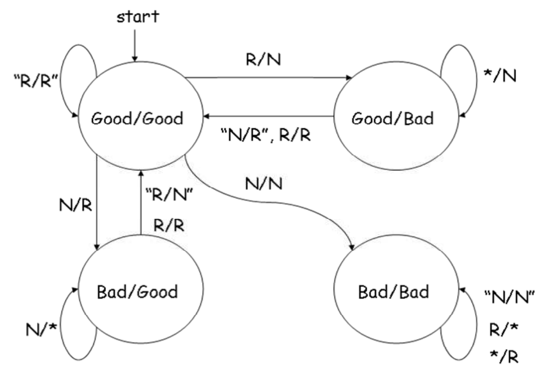

Figure 4: Punish-and-Reward State Diagram

in the next round.

$$u_2(obey|GB) = \sum_{i=0}^{\infty}(-c+b\delta)\delta^{2i} = \frac{-c+b\delta}{1-\delta^2}$$
$$u_2(deviate|GB) = \sum_{i=0}^{\infty}0\delta^i = 0$$

Player 2 will follow the rule if $\delta \geq c/b$ in the $(Good, Bad)$ state. We can have the similar argument for $(Bad, Good)$ state.

Lastly, considering the (Bad, Bad) state, the rule is to play (N, N). Both players do not have incentives to deviate from the system because they will stay in that state regardless of the cooperation.

Since both players start with the $(Good, Good)$ state, they will cooperate if $\delta \geq c/b$. However, if we consider all the states together, players will follow the rule if $\delta = c/b$. □

4.3 Punish-and-Reward System

In punish-and-reward system, we capture the notion of "forgiveness" from the grim-trigger system. Figure 4 illustrates the state diagram of the system. Both players start with the good state like in the previous systems. They enjoy the cooperation until one of them defects. The player who does not relay the opponent's traffic goes to a bad state. It can only restore its "goodness" by receiving a punishment. Here, the punishment is to relay the opponent's traffic.

Since we have forgiveness here, the system is more flexible. In grim-trigger system, if there is a single mistake, then cooperation is impossible thereafter. However, this system allows the player to make up the mistakes.

In the following proposition, we analytically derive the condition that the players will follow the system.

Proposition 3 *Punish-and-Reward System induces the cooperation of players as a subgame perfect Nash equilibrium if $\delta \geq c/b$.*

Proof: Suppose both players are in the good state. Then the rule is to play (R, R) in the next game. If player 1 obeys the system, both players will stay in the good state. If player 1 deviates from the rule and plays (N, R), then it will go to the $(Bad, Good)$ state. It should receive the punishment to get back to the $(Good, Good)$ state again.

$$\begin{aligned} u_1(obey|GG) &= \sum_{i=0}^{\infty}(b-c)\delta^i = \frac{b-c}{1-\delta} \\ u_1(deviate|GG) &= b + \delta(-c) + \delta^2\frac{b-c}{1-\delta} \end{aligned}$$

Player 1 will obey the rule if $\delta \geq c/b$ in the $(Good, Good)$ state. The same argument applies to player 2.

Suppose player 1 is in the good state but player 2 is in the bad state. Then player 1 is supposed to play N and gets the reward. Player 1 will receive the reward from player 2 regardless of its action, and the players will go to $(Good, Good)$ state.

$$\begin{aligned} u_1(obey|GB) &= b + \delta\frac{b-c}{1-\delta} \\ u_1(deviate|GB) &= (b-c) + \delta\frac{b-c}{1-\delta} \end{aligned}$$

Player 1 is always better off to follow the rule.

Now, let's look at the player 2's perspective. Player 2 is supposed to get the punishment and play R. If player 2 obey the rule and receives the punishment (N, R), then it recovers its reputation. Otherwise, it deviates from the rule by (N, N), it stays in the bad state and defers the punishment to following *games.*

$$u_2(obey|GB) = (-c) + \sum_{i=1}^{\infty}(b-c)\delta^i = -c + \delta\frac{b-c}{1-\delta}$$

$$u_2(deviate|GB) = 0 + \delta(-c) + \delta^2\frac{b-c}{1-\delta}$$

Player 2 will follow the rule if $\delta \geq c/b$ in the $(Good, Bad)$ state. We can have the similar argument for $(Bad, Good)$ state.

Lastly, considering the (Bad, Bad) state, the rule is to play (N, N). Both players do not have incentives to deviate from the system because they will stay in that state regardless of the cooperation.

The system will successfully make the cooperation if $\delta \geq c/b$. □

From three propositions above, we can see that the conditions to make players cooperate are the same for all three candidates. However, punish-and-reward system is the most promising one because it is tolerant against some possible mistakes. In addition, it will guarantee the convergence of the overall overlay network.

4.4 Generalized Punish-and-Reward System

We can generalize the idea of punish-and-reward system. Instead of making the punishment just one time, we can think of N consecutive punishments as a make-up for the defecting. Intuitively speaking, we may enforce more players to cooperate as we increase the number of punishments. If the player refuses a punishment during the period, then the punishment procedure starts from the beginning.

The following proposition shows that the system becomes more tolerant against impatient players as we increase the number of punishments.

Proposition 4 *Generalized Punish-and-Reward System induces the cooperation of players as a subgame perfect Nash equilibrium if $\sum_{i=K}^{N}\delta^i \geq c/b$ for $1 \leq K \leq N$.*

Proof: Suppose both players are in the good state. Then the rule is to play (R, R) in the next game. If player 1 obeys the system, both players will stay in the good state. If player 1 deviates from the rule (N, R), then it will go *to the* $(Bad, Good)$ *state. It should receive the* N *punishments to get back to the* $(Good, Good)$ *state again.*

$$
\begin{aligned}
u_1(obey|GG) &= \frac{b-c}{1-\delta} \\
u_1(deviate|GG) &= b + \sum_{i=1}^{N}(-c)\delta^i + \delta^{N+1}\frac{b-c}{1-\delta}
\end{aligned}
$$

Player 1 will obey the rule if $\sum_{i=1}^{N}\delta^i \geq c/b$ *in the* $(Good, Good)$ *state. The same argument applies to player 2.*

Suppose player 1 is in the good state but player 2 is in the bad state. Let K *be the number of punishments left for player 2. Then player 1 is supposed to play* N *and gets the reward. Player 1 will receive the reward from player 2 regardless of its action.*

$$
\begin{aligned}
u_1(obey|GB_K) &= \sum_{i=0}^{K-1} b\delta^i + \delta^K\frac{b-c}{1-\delta} \\
u_1(deviate|GB_K) &= (b-c) + \sum_{i=1}^{K-1} b\delta^i + \delta^K\frac{b-c}{1-\delta}
\end{aligned}
$$

Player 1 is always better off to follow the rule.

Now, let's look at the player 2's perspective. Player 2 is supposed to get the K *more punishments and play* R*. If player 2 obeys the rule and receives the punishment* (N, R)*, then it recovers its reputation. Otherwise, it deviates from the rule* (N, N)*, it stays in the bad state and starts to receive the punishment process from the beginning.*

$$
\begin{aligned}
u_2(obey|GB_K) &= \sum_{i=0}^{K-1}(-c)\delta^i + \delta^K\frac{b-c}{1-\delta} \\
u_2(deviate|GB_K) &= 0 + \sum_{i=1}^{N}(-c)\delta^i + \delta^{N+1}\frac{b-c}{1-\delta}
\end{aligned}
$$

Player 2 will follow the rule if $\sum_{i=K}^{N}\delta^i \geq c/b$ *in the* $(Good, Bad_K)$ *state. We can have the similar argument for* $(Bad_K, Good)$ *state.*

Lastly, considering the (Bad, Bad) *state, the rule is to play* (N, N)*. Both players do not have incentive to deviate from the system because they will stay in that state regardless of the cooperation.*

The system will successfully make the cooperation if $\sum_{i=1}^{N} \delta^i \geq c/b$. □

5 Simulation

In this section, we make some simulation to evaluate one of our proposed methods, punish-and-reward system. First, we want to see if our system actually encourage many cooperations. Also, it is important to check the *price of anarchy*, a metric to measure how much the system is close to the social optimum.

5.1 Parameters

We have three main parameters to set in the simulation:

1. Benefit and cost values: Given a fixed network topology and traffic demand, we may calculate the benefit value using network coordinate systems. However, we have not implemented this feature. For this simulation, we tweak the maximum value of benefit and costs, and use uniform distribution to allocate these values for each pair of the overlay nodes.

2. Number of punishments: We change the number of punishments to see the impact on the coordination ratio.

3. Discount factors: In order to test the tolerance of the system, we use various discount factors.

5.2 Evaluation Metrics

We want to evaluate the system in terms of two factors: cooperation ratio and overall performance.

1. Degree of Cooperation (DoC): This metric simply counts the number of cooperations after the system converges. Clearly, we want to make this metric as high as possible.

$$\text{DoC} = \frac{\text{Number of Cooperations}}{\text{Number of Possible Pairs of Players}}$$

2. Price of Anarchy (PoA): We want to quantify the performance degradation by the absence of central control, which is called *price of anarchy.*

$$\text{PoA} = \frac{\text{Optimal Performance}}{\text{Actual Performance}}$$

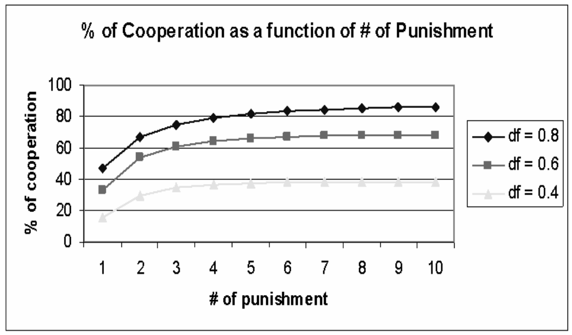

Figure 5: As we put more punishments, more players tend to cooperate. The degree of cooperation converges at some level.

If the performance is close to optimal, it gets close to 1. The value gets closer to ∞ if the performance gets worse.

Another possible metric is fairness. We want the regulation of our system to affect the players as equally as possible. In other words, we want the ratio between actual benefit and actual cost to be as uniform as possible for each overlay node. However, we do not include this metric in this paper.

5.3 Simulation Result

The first question we want to answer is: *Does the system make incentives to cooperate?* In Figure 5, we plot the degree of cooperation as a function of the number of punishments. Following our intuition, more players tend to cooperate as we increase the period of punishments. Interesting thing is that the degree of cooperation converges with a limited number of punishments. It seems that we do not need to that many punishments to stimuate most players.

As the next experiment, we test the price of anarchy as we increase the number of punishments. As shown in Figure 6, the price of anarchy converges, which is simiar to the case of the degree of cooperation.

After the two experiments, we come up with a question: *Is cooperation always good for the social performance?* In Figure 7, we try to find the correlation between the price of anarchy and the degree of cooperation. The simulation shows that there is strong correlation between those factors. Therefore, we can say that encouraging more cooperation will also improve

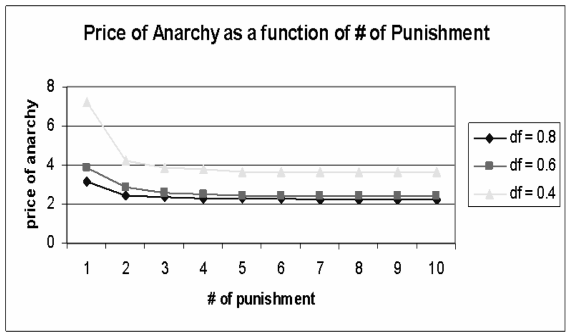

Figure 6: More punishment improves the overall system optimality. Especially, the second punishment significantly improves the performance.

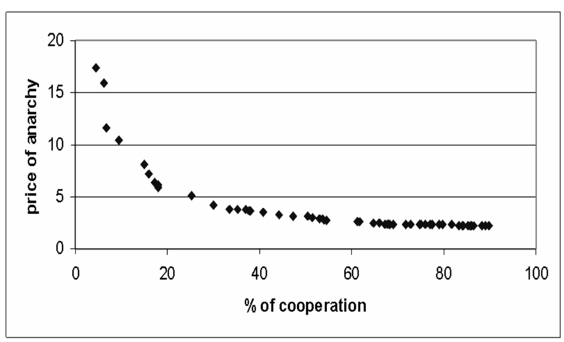

Figure 7: Price of anarchy and degree of cooperation have strong correlation. More cooperations induce better performance.

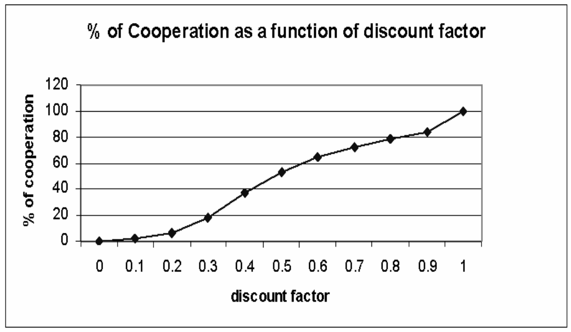

Figure 8: The system shows tolerance to "moderate" players.

the social performance.

Lastly, we want to check the tolerance of the system as we decrease the discount factor (Figure 8). The system shows toleranace for moderate players ($\delta \geq 0.4$). However, as players become extremely impatient ($\delta \leq 0.3$), we could not get good degree of cooperation.

6 Related Work

Incentive-based systems have been extensively researched in networks. Most of all, research on incentives in P2P file sharing systems are distinguishing in [5–9]. Most researches on P2P file sharing system focus on the achievement of optimality by preventing free-riders, which leads to "tragedy of commons."

In [6, 7], non-cooperative game is assumed for explaining self-interested users in P2P networks. In their non-cooperative game, incentives are used for cooperation and helps to achieve the optimal solutions of P2P networks. Two forms of incentives are proposed to measure payoffs such as monetary payments and differential services [8]. [10] introduces explicit incentives into routing and monetary system is proposed. The monetary system seems highly impractical in network society [11]. Thus, [7] proposes differential service model for P2P systems.

[12] characterizes selfishly constructed overlay routing networks and it proves that selfishly characterized overlay networks can present desirable properties with a non-cooperative game model. In [13], a cost-based model is adopted to assess the network resources in overlay networks and the benefits of participating in the overlay networks are explained as a cost reduction.

In [14], market-driven approach to regulate selfish nodes are proposes for the problem of bandwidth allocation in overlay networks.

7 Conclusion and Future Work

In this paper, we analyze the overlay routing in the assumption that the overlay nodes only cooperate each other if there is an incentive to do so. We model the selfish overlay nodes as strategic and rational players to maximize their own utility. The game-theoretic analysis shows that we need some mechanism to encourage the cooperation. We propose three trigger-based frameworks to solve this problem with analytic proof for their feasibility. With sumulation, we show the feasibility of the generalized punish-and-reward system.

In the process of approaching the problem, we introduce some assumptions on the model. Then our direction is to make more realistic model.

First, we assume that the overlay node can forward as much traffic as it wants. However, in reality, every router has some limitation in network bandwidth and computation power. Therefore, we need to add a constraint to the problem.

$$\text{maximize} \sum_{i \neq j} u_{i,j} \text{ , subject to } \sum_{i \neq j} c_{i,j} \leq MAXCOST$$

Another assumption is about the benefit. We have not modeled how these values are set up. Since the network changes dynamically, the benefit values will be changed by the new traffic flow. Actually, the value may change by the overlay traffic by itself because an attractive overlay node may cause congestion to the neighbor links.

Lastly, we assumed that only two overlay nodes are involved in each relation and that those relations are independent from each other. We will capture the correlation in the future work.

References

[1] D. G. Andersen, H. Balakrishnan, M. F. Kaashoek, and R. Morris, "Resilient overlay networks," in *Symposium on Operating Systems Principles*, 2001, pp. 131–145. [Online]. Available: citeseer.ist.psu.edu/andersen01resilient.html

[2] S. Savage, T. Anderson, A. Aggarwal, D. Becker, N. Cardwell, A. Collins, E. Hoffman, J. Snell, A. Vahdat, G. Voelker, and J. Zahorjan, "Detour: a case for informed internet routing and transport, Tech. Rep. TR-98-10-05, 1998. [Online]. Available: citeseer.ist.psu.edu/savage99detour.html

[3] P. K. Dutta, "Strategies and games: Theory and practice," 1999.

[4] F. Dabek, R. Cox, F. Kaashoek, and R. Morris, "Vivaldi: A decentralized network coordinate system," 2004. [Online]. Available: citeseer.ist.psu.edu/article/dabek04vivaldi.html

[5] A. Blanc, A. Vahdat, and Y.-K. Liu, "Designing incentives for peer-to-peer routing," June 03 2004. [Online]. Available: http://citeseer.ist.psu.edu/702477.html;http://www.cs.ucsd.edu/~vahdat/papers/routing-game.pdf

[6] C. Buragohain, D. Agrawal, and S. Suri, "A game theoretic framework for incentives in P2P systems," *CoRR*, vol. cs.GT/0310039, 2003. [Online]. Available: http://arxiv.org/abs/cs.GT/0310039

[7] L. Lai, M. Feldman, I. Stoica, and J. Chuang, "Incentives for cooperation in peer-to-peer networks," in *In Proc. of the First Workshop on Economics of Peer-to-Peer Systems, Berkeley, CA*, 2003.

[8] Golle, Leyton-Brown, and Mironov, "Incentives for sharing in peer-to-peer networks," in *CECOMM: ACM Conference on Electronic Commerce*, 2001.

[9] P. Druschel, "On designing incentives-compatible peer-to-peer systems," June 29 2004. [Online]. Available: http://citeseer.ist.psu.edu/694468.html;http://www.cs.rice.edu/~dwallach/pub/fudico2004.pdf

[10] M. Afergan and J. Wroclawski, "On the Benefits and Feasibility of Incentive Based Routing Infrastructure," in *Proceedings of the ACM SIGCOMM Workshop on Practice and Theory of Incentives in Networked Systems.* ACM Press, 2004, pp. 197–204.

[11] A. Odlyzko, "The history of communications and its implications for the Internet," Manuscript, June 2000. [Online]. Available: http://www.research.att.com/~amo/doc/history.communications0.pdf

[12] B.-G. Chun, R. Fonseca, I. Stoica, and J. Kubiatowicz, "Characterizing selfishly constructed overlay routing networks," in *INFOCOM*, 2004. [Online]. Available: http://www.ieee-infocom.org/2004/Papers/28_4.PDF

[13] N. Christin and J. Chuang, "A cost-based analysis of overlay routing geometries," in *IEEE INFOCOM'05*, March 2005.

[14] W. Wang and B. Li, "Market-driven bandwidth allocation in selfish overlay networks." [Online]. Available: citeseer.ist.psu.edu/717358.html