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Asymmetric Incentives in Peer-to-Peer Systems

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ABSTRACT

In most application scenarios for Peer-to-Peer systems, in order to achieve an overall acceptable system performance an incentive scheme is required that motivates users to share as much as possible of their free resources Today most peers use connections of asymmetric links, such as A-DSL or cable modems. Therefore, users have significantly more download bandwidth than their available upload bandwidth. Applying this observation to incentive schemes suggests that one unit of upload bandwidth should be valued higher than one download unit. Using such an incentive scheme leads the economy of the system to inflation. The incentive scheme would finally collapse. However, by exhibiting the phenomenon of altruistic behavior altruistic peers would accumulate the waste amount of the incentive units. Thus, inflation might be avoided. Gathering the results of a detailed simulative approach, this paper shows how to balance asymmetric incentive schemes in order to avoid inflation.

Keywords

Peer-to-Peer, asymmetric incentives, altruistic behavior

INTRODUCTION

Peer-to-Peer (P2P) systems are based on the assumption that participating peers share their own resources with other peers while they benefit from resources that are shared by others. Through resource replication and utilization of otherwise unused resources, P2P systems can provide much higher robustness and performance at lower costs than traditional client/server-based applications. Emerging P2P file sharing systems like KaZaA and eDonkey host huge amount of content in a reliable way. However, as users have no incentives to share their own resources, there are many free-riders only benefiting from the system and never giving anything back. In consequence, few peers provide most of the content. In the absence of economically efficient mechanisms, which balance the utilization and provisioning of resources, these systems operate with a considerably reduced performance and below the social optimum [13]. In contrast to the centralized solutions, the mechanisms required for P2P systems are much more complicated to be implemented and misusage is difficult to prevent. Today, multiple incentive mechanisms have been presented, e.g. [17, 19, 23]. However, in [13] is was shown that in P2P file sharing some free-riding can be tolerated in the social optimum, which is not addressed by the proposed incentive mechanisms. A weaker incentive mechanism would be appropriate where peers would not be required to provide as much resources as they consume. However, it is a matter of fairness that every peer should still contribute some amount of resources to the system and complete free-riding is not permitted. Further, none of the presented incentive mechanisms addresses the fact that most of today's Internet connections are asymmetric. For example in Europe, a standard DSL-connection has a download bandwidth of 1024 kbit/s and an upload bandwidth of only 128 kbit/s. Therefore, in order to incite users to share resources providing upload bandwidth should be valued higher than using download bandwidth. Indeed, most of the known P2P incentive mechanisms do not allow such asymmetric incentives. The token-based accounting system [14] is flexible enough for this purpose. It uses tokens as a mean of virtual currency and allows to reward users for uploads with payback tokens. In this paper, it is used to study the effects of asymmetric incentives. However, there is one major concern if uploads are valued higher than downloads. Since the transferred amount of data is symmetric - the same amount of data is uploaded as it is downloaded - with every provided service more virtual currency is created. This will lead to inflation and will finally result in a collapse of the incentive system. Due to the P2P paradigm, there is no central currency broker in the token-based accounting system that could control the virtual currency supply. Therefore, another mechanism must be found.

A mechanism that calculates the amount of currency in the system would need to get trustworthy information from each peer about its current amount of virtual currency it own. This introduces an enormous overhead. Therefore, we are looking for a different way to cope with inflation.

In this paper, we want to capitalize altruistic peer behavior to overcome the inflation effect. Altruistic peers would accumulate the additional created tokens and consequently the system may stay in a steady state. This paper shows to which extend altruistic behavior can balance the inflation effect of asymmetric incentives. Simulations are used to analyze different scenarios with different proportions of altruistic peers in the P2P system. Accordingly, the remaining sections of this paper are structured as follows: In the next section, we present the work related to incentive systems. Then we will give a short overview of the token-based accounting system. In Section 4, the simulation model is presented and in Section 5 the simulation results are discussed. Section 6 concludes this paper.

RELATED WORK

Without a working incentive system, P2P systems are threatened to be exploited by free-riders. Measurements about the free-rider problem are published e.g. in [2, 21, 22]. Incentive systems to counter these effects are proposed in several approaches: In [10] a game theoretic approach is presented. In [9] a distributed algorithmic mechanism is suggested. A system with soft incentives for P2P systems (unlike hard incentives as e.g. money) is presented in [1]. The P2P file sharing application MojoNation [15, 16] used a micro payment system to give flexible incentives to users. Fairness in P2P systems is examined in [18]. Further incentive mechanisms are e.g. [17, 19, 23]. A flexible, token-based accounting system that can be used also as an incentive system is presented in [14]. It is used for the analysis presented in this paper. The basics of the token-based accounting system are explained in the following section.

TOKEN-BASED ACCOUNTING SYSTEM

The token based accounting system assumes that users can uniquely be identified through a permanent id, e.g. through a private/public key pair proven through a certificate issued from a certification authority like regulated by [8]. Depending on the application scenario, alternative approaches like [6] are also applicable. Apart from a certificate authority, it is intended to avoid any central element. To implement security, RSA threshold cryptography is applied [10]. RSA based shared keys can be created and updated in a decentralized way [3], [12].

Each peer holds an account with a specific amount of tokens clearly issued to it. A peer spends a token by sending it to its transaction partner in order to receive a service. Accordingly, when a peer provides a service it collects tokens from other peers. Peers cannot spend tokens issued to other peers (the so-called “foreign tokens”). Using the token aggregation process peers exchange the collected foreign tokens against new ones issued to it.

Tokens are issued to a specific peer by including the owner peer’s id. Further, tokens contain a unique identifier and are signed with the peer-to-peer system’s private key. Since a central element for token creation or token signing does not exist, token creation and signing is distributed among peers of the system. The system’s private key is shared among the super-peers of the system. A quorum of super-peers is able to sign new tokens (partially) with the system’s private key using threshold cryptography [7]. The token-based accounting system consists of the three basic protocols: *Token Aggregation*, *Check for Double Spending*, and *Payment* (see Figure 1 to 3).

Token Aggregation

The Token Aggregation process is used to exchange tokens a peer collected against new tokens. Since the basic purpose of this system is accounting and no central authority is used to issue the tokens, they should be traceable to enable control. Therefore, mechanisms to provide anonymity known from electronic cash are not applicable to this scenario [4, 5].

The Token Aggregation procedure is shown in Figure 1. Peers send N collected tokens (Fn_1, ..., Fn_N) to a super-peer that checks the tokens for validity and calculates the amount M of new tokens the peer shall receive in return based on the aggregation function A(Fn_1, ..., Fn_N). The aggregation function is public and can take any form. The super-peer creates M new, unsigned tokens (Un_1, ..., Un_M) and gets them signed with the shared private key by a quorum of super-peers using RSA threshold schemes [10]. The partial tokens (Pn_1, ..., Pn_M) are transmitted to the owner and are combined to new complete tokens Tn_1, ..., Tn_M.

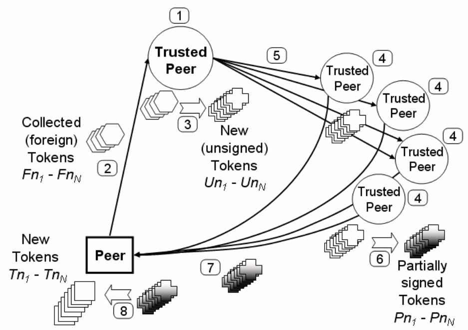

Figure 1. Token Aggregation Protocol

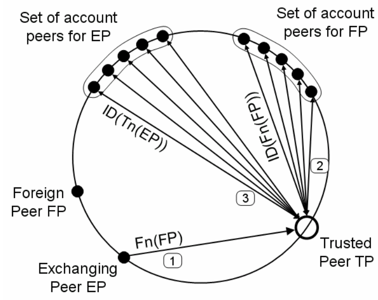

Figure 2. Double Spending Detection

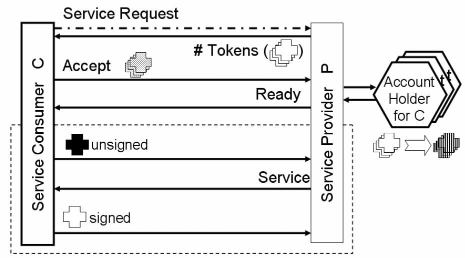

Figure 3. Payment Protocol

Check for Double Spending

As described in the prerequisites, we assume that every peer owns a private/public key pair that uniquely identifies the peer. Before sending a token, a peer adds the required accounting information to the token and signs it using its private key. Only tokens that are signed by the owner-peer are valid for aggregation. The receiving peer only accepts valid tokens with correct accounting information. Otherwise, it stops the service. A token is valid if it is signed with the shared private key and has not been spent before. To check for double spending, a token must uniquely be identifiable. The token id consists of the token owner id, the issuing date and time, and a sequence number.

The double spending mechanism requires for each peer an additional account on a remote peer. For efficiency reasons, the account-holding peers are organized using a DHT-based overlay structure based on Pastry [20]. The remote account contains a list of tokens issued to the account owner. The list of the ids of the issued tokens is sent to the account-holding peer during the Token Aggregation phase. Prior to each transaction, the customer peer notifies the providing peer which tokens it intends to spend within the transaction. The providing peer asks the account-holder whether these tokens are valid. In the token list, during this step valid tokens are marked as spent and finally removed from the list when exchanged in an aggregation process. This way double spending cannot only be detected and traced to the source but it also can be avoided (see Figure 2).

Payment

The accounting system supports the following trustworthy way for the exchange of content and tokens. Tokens are sent in two parts. Before the service is provided, a token is sent without the owner's (customer peer's) signature. Now the provider peer provides the service. Finally the customer peer fills into the token the required accounting information, signs the token and sends it over to the provider . If the customer peer fails to deliver the final part of the token, the providing peer cannot use the incomplete token for token aggregation. However, the token will be marked as spent. Both peers lose their incentive to cheat. A reputation system will provide further incentives against malicious behavior.

For more details about the token-based accounting system we refer to [14].

SIMULATION MODEL

The goal of the simulation model is to determine if in a P2P file sharing scenario asymmetric incentives make sense. Thus, an asymmetric incentive system must fulfill two criteria. On the one hand, no inflation must occur when asymmetric incentives are used in order to ensure that the incentive scheme is stable over time and its effects are not diminished. On the other hand, it must be shown that the asymmetric incentive mechanism is functioning, i.e. it has an affect on user behavior.

To implement asymmetric incentives into the P2P system we use the token-based accounting system by choosing an aggregation function different than

$$N = F, \text{ where } N = \text{amount of new tokens}, F = \text{amount of exchanged foreign tokens}$$

To value an upload twice as high as an download the aggregation function would be set to $N = 2F$.

To assess if inflation occurs in the system we have to define a condition to determine which tokens are still used for trading in the system and which not. I.e., we have to determine which tokens belong to the cash flow in the system.

To assess whether the incentive system is still functional we have to determine if peers' file sharing behavior is improved in comparison to peers' file sharing behavior without incentive system. In order to accomplish that we have to define peer behavior models for strategic peers and for altruistic peers.

Peer behavior models

To model realistic peer behavior, three different file sharing behavior models are used. Each peer belongs to one of the following peer classes:

- Strategic peers that do not share any files voluntarily. They represent free-riders.
- Normal peers that merely share a small number of files. They correspond to peers that download files and share them afterwards for some time.
- Altruistic peers that share all files they have.

In our model, we assume that peers upload all files that requested from them. Therefore, in our model the goal of an incentive system is to motivate normal peers and strategic peers to share more files.

Inflation detection

To determine whether inflation occurs in the system, the amount of tokens available to the peers targeted by incentive system must be calculated. If this number increases over time then inflation of tokens occurs. Typically, the peers targeted by the incentive systems are the strategic peers and the normal peers. Altruistic peers share their files independently of the presence of an incentive system. Therefore, altruistic peers are expected to accumulate tokens. These accumulated tokens are not available to the system anymore. In order to decide which tokens are still available to the system we defined that the tokens available to the systems are represented by the own tokens in the system. Further, we defined that the tokens not available to the system are represented by the foreign tokens in the system. Thus, in the simulation peers exchange received foreign tokens immediately back to own tokens, and plan to spend them again. Accordingly, in the simulation foreign tokens represent the tokens that are not available in the system anymore. Therefore, for every behavior model a different exchange policy must be defined:

- Strategic peers exchange all received foreign tokens immediately back to own tokens.
- Normal peers target to have always available a specific amount of own tokens.
- Altruistic peers also want to download from the P2P system. Therefore, they also try to have a specific amount of own tokens available.

By applying these rules for file sharing and inflation detection, it can be argued that strategic peers do not accumulate any tokens. They merely spend tokens for downloading files. However, they only receive tokens when they share files (what they normally do not do). On the other hand, altruistic peers will accumulate tokens, while normal peers always share a small number of files. The purpose of the incentive system is to motivate all peers to share more files. Therefore, normal peers could also accumulate tokens. However, that would mean the incentive system is not working for the normal peers anymore. Accordingly, the amount of foreign tokens normal peers hold is a measure for the degree of inflation in the P2P system.

Further, a metric for the efficiency of the incentive mechanism is needed. The purpose of the incentive system is to motivate peers to share more files. Accordingly, the amount of additional files normal share and the amount of files foreign peers share is the measure of the efficiency of the incentive mechanism.

To evaluate the described peer behavior model a simulator was used that will be now described in detail.

Simulator

The simulator implemented for this paper is round-based. At the beginning of every round, each peer has a specific number of own tokens T and foreign tokens F and shares a specific number of files f. In addition, each peer belongs to one of the three behavior classes. In this work we want to assess for which percentages of altruistic and strategic peers asymmetric incentives can be applied. Accordingly, the behavior class is invariable for each peer. During each simulation round for each peer it is determined whether it wants to download a file based on a predefined download probability. If so, it is determined which file the peer wants to download as well as the provider peer. Each file has a specific price *p* in tokens. In this simulation the focus is on the inflation of the system not on file distribution. If we assume that according to their popularity files are evenly distributed among the behavior classes and that the interest in these files is also evenly distributed among the behavior classes, we can conclude, that file popularity does not influence the inflation effect. Therefore, file popularity is not modeled. A download takes place if the requestor peer has enough own token to pay the provider. Then the provider receives an amount of foreign tokens that is equal to the file price *p*. The same amount of own tokens is subtracted from the customer's own tokens. If the customer does not have enough own tokens to afford the download, the peer shares an additional amount of file *f'* in order to receive more upload requests. In the next round, the peer will try again to download the file. If it still does not have enough own tokens, it will again share some more files. This continues until the download request is successful. At the end of each round, peers' foreign tokens are exchanged against own tokens according to the peer's behavior class' exchange policy. In addition, the amount of shared files is adjusted. If a peer downloaded a file successfully, the file sharing policy according to the behavior model is applied. Otherwise, the peer will share additional files, as described before. Finally, for each peer class the amount of tokens and shared files is calculated for evaluation purposes. Peer up-time is not modeled in the simulation. If we assume that peers show the same up-time behavior in all behavior classes, then on average the percentages of peers of the behavior classes in the system are invariable. Accordingly, peer up-time will not have an influence on the inflation effect.

Simulation scenarios

In every simulated scenario, peers start with 25 own tokens and no foreign tokens. Each peer starts with a certain number of own files; this number is uniformly distributed between 5 and 100. The files have a normal distributed price with a mean of 5 and a standard deviation of 3. Altruistic peers share all of their files. Normal peers share a random number of files, which has a Normal distribution with a mean of 10 and a standard deviation of 5. Peers want to download a single random file in a simulation round with a probability of 25%. Altruistic and normal peers exchange 15 foreign tokens to own tokens as soon as their balance of own tokens falls below 20. For the presented results, systems with 1000 peers have been simulated with varying ratios of altruistic, normal, and strategic peers. In empirically observed file sharing systems, there are approximately 10% to 20% altruistic peers according to [2, 11]. Strategically acting peers form the majority. The parameters of the simulated scenarios are provided in Table 1.

Behavior Classes			**Exchange Function**		
Altruistic	Normal	Strategic	Upload	Download	**Comments**
10%	30%	60%	-	-	No incentive system for comparison
10%	30%	60%	1	1	Symmetric incentives for comparison
10%	30%	60%	1,5	1	
10%	30%	60%	2	1	
10%	30%	60%	3	1	
10%	30%	60%	1	2	Valuing downloads higher than uploads to force more uploads
20%	30%	50%	-	-	No incentive system for comparison
20%	30%	50%	1	1	Symmetric incentives for comparison
20%	30%	50%	1,5	1	
20%	30%	50%	2	1	
20%	30%	50%	3	1	

Table 1. Conducted Simulations

RESULTS

Figure 4 shows the inflation in a P2P system with 60% strategic peers and only 10% altruistic peers. Inflation occurs for exchange functions 2:1 (uploads are valued twice as high as downloads) and 3:1. For an exchange rate of 1,5:1 the system stabilizes at approximately 4,5 foreign tokens per peer on average. The amount of own tokens for normal peers stabilizes at approximately 16 tokens (as expected due to the exchange rules). For symmetric incentives (exchange function 1:1), normal peers have 5 foreign tokens on average. A scenario where downloads are valued higher than uploads to encourage peers much stronger to share files also has been also investigated. However, this reduces the amount of tokens in the system leading very soon to a situation where no tokens are left in the system and no sharing is possible anymore. Such scenarios do not make sense.

Figure 5 shows the inflation in a P2P system with 50% strategic peers and only 20% altruistic peers. In comparison to the scenarios with 10% altruistic peers, the inflation is slightly reduced. Also here with an exchange function of 1,5:1 the system stabilizes.

Figure 6 shows the development of sharing files of the normal peers. For an incentive free scenario, a normal peer shares on average 7 files (labeled “no” in Figure 6). For the scenario with symmetric incentives, a normal peer shares initially 7 files and after 1000 simulation rounds 246 files. These two scenarios form the lower and the upper bounds for asymmetric incentive scenarios. The scenarios 2:1 and 3:1 perform better than the scenario without incentives. However, the amount of files normal peers share is reduced by approximately 65% in comparison to the symmetric incentives scenario. The stable asymmetric scenario (exchange function 1,5:1) performs as good as the symmetric scenario. Similar observations can be made for a 20% proportion of altruistic peers as Figure 7 shows.

Figure 8 shows the development of sharing files of the strategic peers. Here, similar results as for the file sharing of normal peers can be observed. Figure 9 shows again only slight differences when the proportion of altruistic peers in the system increases to 20 %.

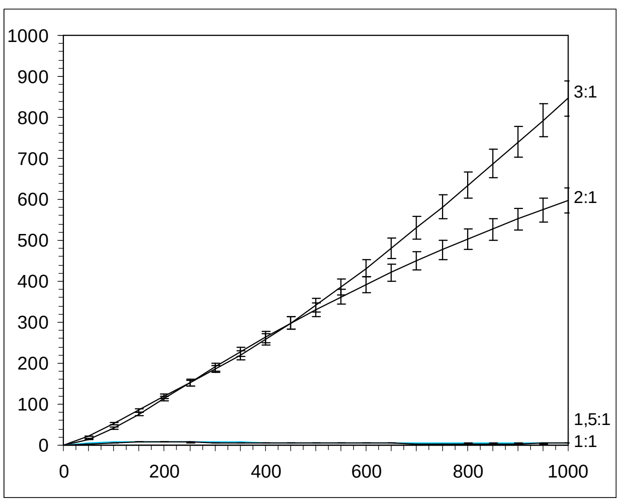

Figure 4. Normal peers' foreign tokens (average per peer) for 60% strategic peers

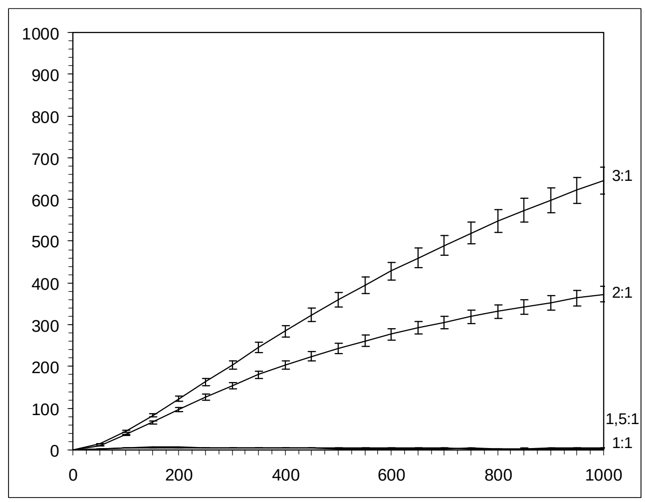

Figure 5. Normal peers' foreign tokens (average per peer) for 50% strategic peers

According to these observations, it can be concluded that altruistic peers can compensate the inflation effect if the ratio for asymmetric incentives is more than 2:1. In addition, it can be seen that even for higher asymmetric incentive ratios the incentive mechanism still has a positive effect on peers file sharing behavior. The incentive mechanism still accomplishes its purpose.

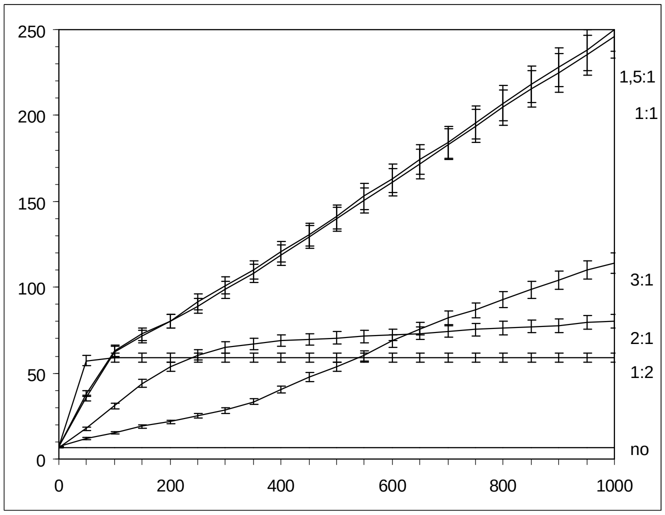

Figure 6. Normal peers' shared files (average per peer) for 60% strategic peers

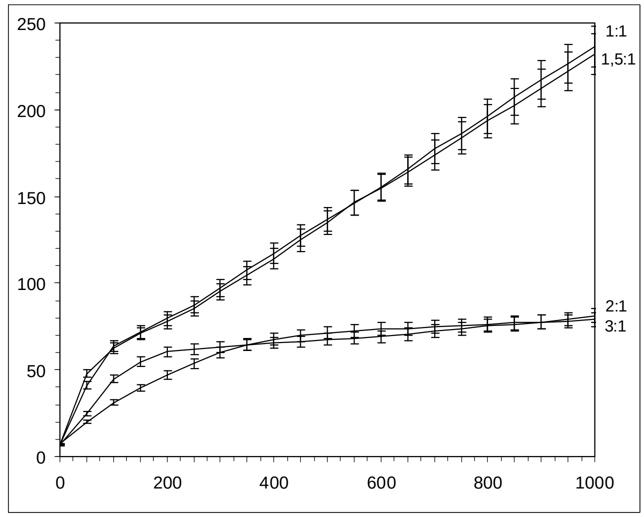

Figure 7. Normal peers' shared files (average per peer) for 50% strategic peers

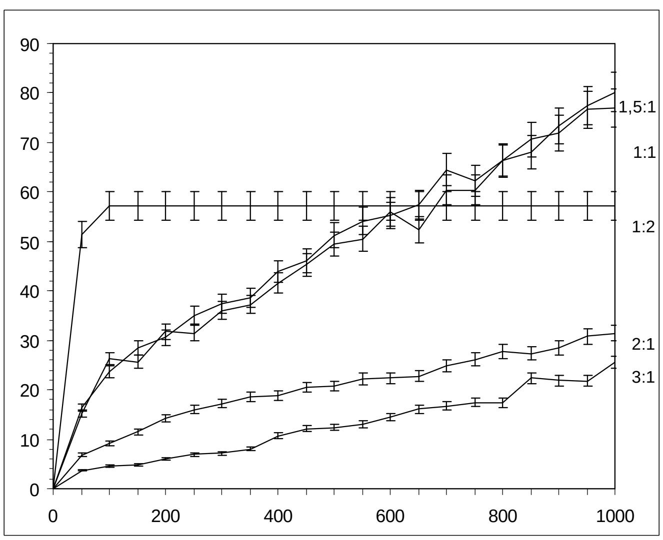

Figure 8. Strategic peers' shared files (average per peer) for 60% strategic peers

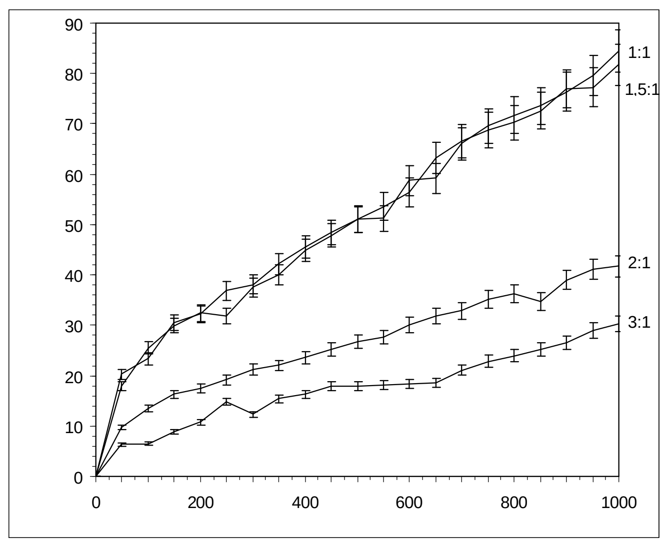

Figure 9. Strategic peers' shared files (average per peer) for 50% strategic peers

CONCLUSIONS

P2P systems are based on the assumption that participating peers share their own resources with other peers. However, file sharing applications have shown that only a minority of peers share their resources voluntarily. This reduces the system performance considerably and the system operates below the social optimum [13]. Therefore, incentive schemes are needed. They motivate or even force users to share more resources. However, at the social optimum free-riding can be tolerated to a specific degree. Therefore, an incentive scheme does not need to be strict, i.e. not all peers need to provide at least as many resources as they consume. However, as a matter of fairness every peer should still contribute some amount of resources to the system and complete free-riding should not be permitted. Further, today's Internet connections are in their majority asymmetric. Thus, the rationale to introduce asymmetric incentives to allow a specific degree of free-riding and to value an upload higher than a download is obvious. However, inflation of the virtual currency used to introduce incentives might occur. Due to the P2P paradigm there is no central broker in the system that could control the virtual currency supply. Altruistic peers that accumulate the surplus currency counteract the inflation effect. This paper showed how to configure asymmetric incentives in order to compensate the inflation effect.

The key finding of the conducted simulation is that the inflation effect for asymmetric incentives with ratios of 2:1 and higher can not be compensated by realistic proportions of altruistic peers. However, it was shown for asymmetric incentive ratios below 2:1 (and above 1:1), the inflation effect is compensated and the system evolves to a steady state. This is true for all different percentages of altruistic peers we simulated. Thus, here altruistic peers seem to offer a natural way to cope with inflation. With different percentages of altruistic peers (and incentive ratios below 2:1) the system evolves at a steady state because the resulting sharing behavior of the strategic peers differs. Further, it was shown that even with higher asymmetric incentive ratios than 2:1, peers show considerably improved file sharing behavior, which fulfills the main goal of an incentive system.

Further research steps are to find the exact ratios of asymmetric incentive systems where inflation starts to occur. In addition, asymmetric incentive ratios that lead to inflation have to be investigated more deeply. It is interesting to explore whether in the long term the (initially) improved file sharing behavior might degrade again. Further, it is interesting to explore how the distribution of popular files in influenced by different asymmetric incentives.

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