When Can an Autonomous Reputation Scheme Discourage Free-riding in a Peer-to-Peer System?

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We investigate the circumstances under which it is possible to discourage free-riding in a peer-to-peer system for resource-sharing by prioritizing resource allocation to peers with higher reputation. We use a model to predict conditions necessary for any reputation scheme to succeed in discouraging free-riding by this method. We show with simulations that for representative cases a very simple autonomous reputation scheme, the Network of Favors, works nearly as well at discouraging free-riding as an ideal reputation scheme. Finally, we investigate the expected dynamic behavior of the system when a reputation scheme is used.

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Abstract

We investigate the circumstances under which it is possible to discourage free-riding in a peer-to-peer system for resource-sharing by prioritizing resource allocation to peers with higher reputation. We use a model to predict conditions necessary for any reputation scheme to succeed in discouraging free-riding by this method. We show with simulations that for representative cases a very simple autonomous reputation scheme, the Network of Favors, works nearly as well at discouraging free-riding as an ideal reputation scheme. Finally, we investigate the expected dynamic behavior of the system once using a reputation system.

1 Introduction

Peer-to-peer systems [11] can be an effective and robust way of sharing resources. However, the effectiveness of several existing peer-to-peer systems is diminished by widespread free-riding [1, 12, 13]. A peer that is a free-rider consumes resources donated by others but does not donate any resources itself. If there is a nonzero cost of donation, and the system does not discriminate between free-riders and other peers, then peers have an economic incentive to become free-riders, thus reducing the resources available for donation in the community, and diminishing the utility of the system as a whole.

One potential solution is to introduce a reputation scheme to the system. The interactions between peers affect their reputation in a way designed so that free-riders are unlikely or unable to build up a high reputation. When a peer has a resource to donate, and there are several peers requesting this resource, the peers with higher reputation are given priority. The idea is that the advantage that this gives to peers who donate resources may be enough to overcome the disadvantage given by the cost of donation.

This use of reputation differs from the classic use of reputation schemes to enhance the quality of transactions in peer-to-peer systems such as eBay [6], or to marginalize untrustworthy peers as in the systems surveyed by Ooi et al. [10]. If reputation is used to discourage free-riding then the choice to interact with a peer with high reputation is made in order to reward the peer for its previous behaviour, rather than to enhance the expected quality of the immediate transaction.

We are particularly interested in the circumstances under which it is possible to discourage free-riders using an *autonomous* reputation scheme. In an autonomous reputation scheme, peers use only local information to prioritize other peers. As such, they can only access reputation information involving peer-to-peer interactions in which they themselves have participated. The reputation of a given peer will in general be different in the eyes of different peers, and there is no attempt to reconcile these local reputations to create a global assessment. As a result, autonomous reputation schemes are relatively simple to implement, and do not require a cryptographic infrastructure or centralized storage to guarantee integrity of data retrieved from other peers, as is the case for some other reputation schemes that assign a single global reputation value to a peer. Autonomous reputation schemes are used for various purposes in the peer-to-peer resource-sharing networks BitTorrent [5], eMule [7] and GNUnet [8] and OurGrid [3].

An alternative way of using a reputation scheme to discourage free-riders would be not to give peers with low reputation low priority access to donated resources, but to refuse to donate resources altogether to peers with reputation below some chosen limit: if a peer had resources to donate but only peers with low reputation requested them, then the resources would remain undonated. However, this alternative would cause bootstrapping problems for an autonomous reputation scheme, because a new collaborator entering a system with autonomous reputation can only show that it is not a free-rider by donating resources, and can only detect that another peer is not a free-rider by being donated resources by that peer. Hence in this paper we consider the effect when the reputation scheme is used to prioritize donations rather than to ban certain kinds of donation completely.

In [2, 3] we described an extremely lightweight autonomous reputation scheme, the Network of Favors. This was designed to promote equitable resource sharing in OurGrid, a peer-to-peer system that we are currently developing for sharing CPU cycles for bag-of-tasks applications [4]. For this autonomous reputation scheme, the reputation of peer $P1$ in the eyes of peer $P2$ is equal to the total value of resources that $P2$ has donated $P1$, minus the total value of resources that $P1$ has donated $P2$ - or is zero if this value is negative. We showed in [2] that this reputation scheme is effective at discouraging free-riders if the peer-to-peer system exhibits eager consumption, that is, if peers that are in consuming state have no limit on the amount of resources they can use with positive utility. In this paper we no longer assume that there is eager consumption. Non-eagerness may be realistic if the resource being shared is for example CPU time for applications that are not easily parallelizable, or is access to a particular software application. We explore the design space for a non-eager peer-to-peer system in which it is possible to discourage free-riding by prioritizing resource donations using an autonomous reputation scheme.

We define a free-rider as a peer that does not contribute resources to the system, and a *collaborator* as a peer that does contribute resources. We say that *the system works* at time t if at that time there is a disincentive for collaborators to change their strategy to free-riding: in other words, if the expected utility for a collaborator is greater than the expected utility the collaborator would have if it changed strategy. Free-riders always have an expected utility at least as great as the expected utility that they would have outside the system, and so if the system works then the expected utility for collaborators in the system is greater than their expected utility if they left the system.

In this paper we assume that peers in consuming state can be donated resources by any collaborator in donating state. This implies that the resources are interchangeable, which can be the case if the system shares generic CPU time, or bandwidth, or storage. However the analysis of this paper may not extend to peer-to-peer systems sharing less generic resources, such as data files, because a peer requesting a specific file will not in general be able to receive it from any peer currently donating resources, only from those peers currently donating resources that have a copy of the file. However, measurements of large scale peer-to-peer file-sharing systems [9, 13] have found that a large percentage of all requests are for a relatively small number of files. For each one of these popular files, we can consider the peer-to-peer virtual subsystems consisting of requests for and donations of the file. Within each of these subsystems the resources are interchangeable. It is intuitively reasonable that if each of these virtual subsystems satisfies conditions that allow a particular reputation system to drive out free-riding, then by using the reputation system for the prioritization of donations in the file-sharing system as a whole it should be possible to discourage peers with typical resource requirements from free-riding. A more precise analysis of the circumstances in which a reputation scheme can be used to discourage free-riding in a file-sharing system is beyond the scope of this paper.

The rest of this paper is structured as follows. First we describe the system model. Then we analyze the conditions on system parameters for the system to work at a fixed time, and use this analysis to predict system behaviour for some representative scenarios. We then simulate these scenarios and check that the predictions are met, and compare the performance of the Network of Favors with that of an ideal reputation scheme in the simulated scenarios. Finally, we investigate the dynamic behaviour of the system if peers change their strategies according to their own economic interest.

2 System model

We consider a peer-to-peer system comprised of a set of collaborators and free-riders. At a fixed time t, a peer can be either in consuming or in non-consuming state. When in non-consuming state, collaborators donate their resources, while free-riders go idle. The design parameters that we consider for the peer-to-peer system are:

- Eagerness. We assume that for each peer there is a maximum value $C > 0$ of the utility of resources that can be consumed during a unit time interval when the peer is in consuming state. Thus, C limits the amount of resources that can be useful for a peer. The value of C is fixed for a given peer, but may vary between peers, with average value $\overline{C}$.

- The probability ρ of a peer being in consuming state. We assume that at a given time each peer has an independent probability ρ of being in consuming state.

- Cost of donation. The utility lost to the donator as a result of donation is a constant v times the utility gained by the recipient as a result of the donation, with $0 < v < 1$. If resources are available for donation but are not donated, no utility cost associated with these resources is incurred by the resource owner.

- Value of donation. When a collaborator (that is, a peer that is not a free-rider) is not in consuming state, it has resources of value D available to donate to the system. We assume that the value of D is fixed for a given peer, but can vary between different peers, with average value $\overline{D}$.

- The proportion f_t of peers that are free-riders at time t. The value f_t lies between 0 and 1. At time t, $N.f_t$ peers will be free-riders and $N.(1-f_t)$ collaborators, where N is the total number of peers in the system.

For our analysis and simulations we will assume that all the values of the variables other than f_t are fixed over time.

The protocol for donation of resources is that collaborators that are not in consuming state donate all the resources that they have available as long as there are peers in consuming state prepared to consume them. Peers with high reputation are given priority in donations. We assume that the granularity of resources is low enough that a donating peer with at least as many spare resources as a consuming peer requests is able to give exactly the amount of resources requested, if the donating peer wishes to do so. Any resources left over, after all peers in consuming state have been donated the maximum amount of resources that they are prepared to accept, are not donated. Collaborators with resources to donate at a particular time do not have to donate them all to the same peer: they can donate resources to several different requesting peers. Free-riders that are not in consuming state stay idle.

3 Analysis

In this section we calculate the values of design parameters for which the reputation system succeeds in discouraging free-riding, and use approximations to give predictions for the behaviour of sample scenarios.

Recall that we say that the system works at time t if at that time there is a disincentive to collaborators to change their strategy to free-riding. Define the *advantage to collaborators* at time t as the expected utility gain to a collaborator as a result of being in the system minus the expected utility gain to a free-rider. This is a measure of how much free-riding is discouraged at time t. It will in general be a function of f_t. The system works at time t with $f_t = f$ if and only if either $f \in (0, 1)$ and the advantage to collaborators is positive at $f_t = f$, or $f = 0$ and the limit of the advantage to collaborators as $f_t \to 0$ is positive.

Initially we pick a fixed time t, and calculate whether the system works at that time. Later on (in Section 5) we will discuss the dynamic behaviour of the system.

3.1 Analysis for fixed time

For this subsection we will assume that the reputation scheme is able to identify free-riders perfectly, that is, any free-rider always has a lower reputation than any collaborator.

Suppose at a fixed time t the total value of resources offered for donation is x_d (and that this is greater than zero), the total value of resources requested by collaborators in consuming state is x_c, and the total value of resources requested by free-riders in consuming state is x_f. We distinguish three cases, a *famine* of donations, a *glut* of donations, and the *middle* case.

The condition for famine is $x_d \leq x_c$. If this holds, then free-riders receive no donations, so gain utility zero by being in the system, whereas the set of collaborators gains a total utility $(1 - v).x_d > 0$ by being in the system. Therefore the advantage to collaborators is positive, and the system works at time t.

The condition for glut is $x_d \geq x_c + x_f$. If this holds, then all peers who make a request at time t will be donated all the resources they request. The expected utility gain for a peer resulting from the resources it is donated depends on C, but does not depend on whether the peer is a collaborator or a free-rider. On the other hand, a collaborator has an expected utility cost resulting from the resources it donates. So a collaborator can increase its overall expected utility by changing its strategy to free-riding. Therefore the advantage to collaborators is negative, and the system does not work at time t.

The condition for the middle case is that there is neither famine nor glut, ie. $x_c < x_d < x_c + x_f$. In this case the total utility gain by the set of collaborators is $x_c - v.x_d$, and the total utility gain by the set of free-riders is $x_d - x_c$. If $x_c \leq v.x_d$, then clearly the advantage to collaborators is non-positive and the system does not work at time t. Suppose $x_c - v.x_d$ is positive and $f_t \in (0,1)$. Then the advantage to collaborators is

$$\frac{(x_c - v.x_d)}{(1-f_t).N} - \frac{(x_d - x_c)}{f_t.N} \quad (1)$$

which is a monotonically increasing function of f_t that tends to minus infinity as $f_t \to 0$. So the system does not work at time t for $f_t = 0$, and works for $f_t \in (0,1)$ if and only if the value of this function is positive.

So far we have assumed that there is non-eager consumption. But a similar argument can be used if there is eager consumption. Eager consumption can be modeled by putting $x_c = \infty$. This implies that the condition for famine holds, whatever the values of the other variables, and hence the system works if there is eager consumption.

In the analysis we have not assumed that the allocation of resources to requesting collaborators is proportional to the amount that these collaborators have donated. However, if it is, if there is famine and a collaborator acquires some new spare resources additional to its original resources of value D, then the collaborator has an incentive to donate these new resources to the community, provided that doing so will not move the system out of the famine condition.

We now use the results of this analysis to pick some representative scenarios for the system parameters, and make predictions for the behaviour of the system for these scenarios.

3.2 Predictions for sample scenarios

The mean values of x_d, x_c and x_f can be expressed in terms of the design parameters as $(1-\rho).\overline{D}.(1-f_t).N$, $\rho.\overline{C}.(1-f_t).N$, and $\rho.\overline{C}.f_t.N$ respectively. We can estimate whether the system will work or not at a fixed time for a given set of parameter values, by determining whether the system will work for the mean values of x_d, x_c and x_f. This is only an estimate, because the actual values fluctuate statistically about these values, but this is a reasonable approximation to make because small changes in these values will result in small changes in the utilities we calculate. (The approximation is less accurate if D varies widely between peers.)

The scenarios we choose are the ones where the parameter values satisfy $\overline{D} = 10$, $C = 9D$ for each peer, $C = D$ for each peer, or $C = D/10$ for each peer (recall that D may vary from peer to peer); $\rho \in \{0.1, 0.5, 0.9\}$; $f_t \in \{0.25, 0.5, 0.75\}$; and $v \in \{0.1, 0.4\}$. This makes a total of 3 x 3 x 3 x 2 = 54 sets of parameter values.

We have chosen these values to be realistic, to include both low and high realistic values, and to include some scenarios where the mean values of x_d, x_c and x_f are on the borderline between different cases.

Our prediction, using the estimate given by taking the mean values and applying the analysis of the previous subsection, is that among these 54 sets of parameter values, assuming perfect identification of free-riders, the system will work just for the 36 sets of parameter values that satisfy $C = 9D$, or $C = D$ and $\rho = 0.9$, or $C = D$ and $\rho = 0.5$, or $C = D/10$ and $\rho = 0.9$. For the scenarios satisfying one of the first three alternatives there is famine for the mean values, and the scenarios satisfying $C = D/10$ and $\rho = 0.9$ the mean values are in the middle case with positive advantage to collaborators.

Clearly, if the system will not work for an ideal reputation system that has perfect identification of free-riders, it should not work for a weaker reputation scheme. The Network of Favours does not in general give perfect identification of free riders, so for the Network of Favors we predict that the system will work for a subset of the 36 sets of parameter values identified above.

4 Simulations

We now turn to simulations for the design parameters above. We aim to investigate the effectiveness of the Network of Favors in providing a positive advantage to collaborators in the scenarios for which the analysis of the last section predicts that it is possible for a reputation scheme to do so. In order to provide a reference system, we simulated an ideal reputation scheme that perfectly identifies all free-riders. We need such a simulated reference system due to the statistical fluctuations in x_d that the simulations provide. Because of these fluctuations, the results of a perfect reputation scheme are not identical to the analytical prediction.

In our simulations, the timeline is in turns, and at each turn each peer has an independent probability ρ of being in consuming state. We ran the scenarios described in Subsection 3.2 with the value of donation $D = 10$ for all peers, both using the Network of Favors and using the ideal reputation scheme.

For both the Network of Favors and the ideal reputation schemes the advantage to collaborators in the simulations was positive for 35 of the 36 scenarios the analysis had predicted it would be positive. Also, for 29 of these 35 scenarios the behavior of the Network of

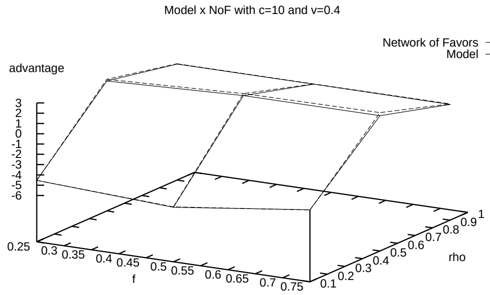

Figure 1. Advantage to collaborators in the scenarios where $C = D$ and $v = 0.4$, varying ρ and f.

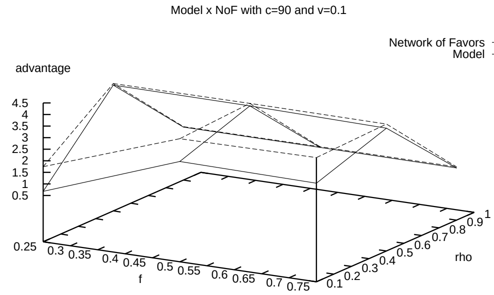

Figure 2. Advantage to collaborators in the scenarios where $C = 9D$ and $v = 0.1$, varying ρ and f.

favors was close to the behavior of the ideal reputation scheme simulated. Figure 1 illustrates the comparison of the advantage for collaborators between a system using the Network of Favors and an ideal reputation scheme for some of these scenarios, where the eagerness level $C = D$ and the cost of donation $v = 0.4$.

The scenarios where the difference between the Network of Favors and the ideal reputation scheme was significant were all the scenarios in which $C = 9D$ and $\rho = 0.1$. This difference is illustrated in Figure 2. The scenarios in which $C = 9D$ and $\rho = 0.1$ are on the border between the famine and the middle case, so the statistical fluctuations in x_d have a greater impact on them. Indeed, it was in these scenarios that the advantage to collaborators found in the simulation using the ideal reputation scheme differed most from the the values predicted by our analysis, and also differed most from the values found in the simulation using the Network of favours.

The sole scenario in which the system did not work using the Network of Favors when the analysis predicted that it would using a perfect reputation scheme was the one with $C = 9D$, $\rho = 0.1$, $f = 0.25$ and $v = 0.4$. This scenario is also in the border between the famine and the middle case, and setting $f = 0.25$ and $v = 0.4$ is enough to give a negative advantage to collaborators under the Network of Favors. Note that these two parameter values define a scenario where there is a relatively large cost of donating resources, and few free-riders to share the resources they manage to get. The ideal reputation scheme, however, did not perform much better in the simulation of this scenario: its advantage for collaborators stays fluctuating around zero when the system reaches steady state. So, according to our definition, even when using a reputation scheme that perfectly identifies free-riders, the system did not work all the time in this scenario.

As a second step, we introduced some new scenarios where peers do not have the same D (and, hence, not the same C) or the same ρ. We investigated the cases where either D or ρ is given by the uniform distributions $U(1, 19)$ or $U(0.1, 0.9)$, respectively.

When D was given by a uniform distribution with mean 10 there was the same overall behavior as when D was set equal to 10 for all peers, and making ρ different for different peers had only a slightly greater impact. Although the mean value of ρ was equal to 0.5 in all our scenarios, the difference between the performance of the system in providing incentives for collaborations using Network of Favors and using an ideal reputation scheme was greater in the scenarios where different peers had different values of ρ. More specifically, the statistical fluctuations in x_d made the difference in performance greater for the scenarios where $C = D$ and $f = 0.25$ and made the system not work when using the Network of Favors in the two scenarios where $C = D$, $v = 0.4$, $\rho = U(0.1, 0.9)$ and $f \in \{0.25, 0.5\}$. Once again, these scenarios are on the border between the famine and middle cases. The statistical fluctuations in x_d arising from the differing values of ρ regularly pushed the system into the middle case, in which the Network of Favors is less efficient at rewarding collaborators. When combined with the high cost of donation $v = 0.4$, the effect was that the advantage to collaborators was negative for the Network of Favors in these scenarios.

Still, the system using the Network of Favors performed similarly to one using an ideal reputation scheme in almost all scenarios of our experiment where we predicted that any reputation had a chance of being effective (including 35 out of our original 36 scenarios with fixed ρ and D). With the exception of three scenarios where the Network of Favors proved to have a slightly different tolerance for non-contention of resources, it made the system work whenever an ideal reputation scheme would. Moreover, for the great majority of scenarios, there was only a very small difference between the measured advantage for collaborators in a system using the Network of Favors and in a system using the ideal reputation scheme.

This shows, at least for the scenarios that we simulated, that in most of the cases where it is possible to use an ideal reputation scheme, it is also possible to use the Network of favors without a great loss in performance. With the exception of the three border scenarios with large donation costs, although it sometimes did not perform as well as the ideal reputation scheme, the Network of Favors still managed to provide a positive advantage to collaborators whenever the ideal reputation scheme did so. We had imagined that more complex centralized reputation schemes with global assessments of reputation would give a significantly greater advantage to collaborators than the Network of Favors, but this appears not to be the case.

Note that our comparisons between the two reputation schemes were all made after the system using the Network of Favors had reached a steady state. A system using the Network of Favors requires some time to reach a steady state in which it has an accurate identification of free-riders. As a result, before the system reaches this state the Network of Favors should have less effect than the perfect reputation system in discouraging free-riding.

In [2] we investigated the time for a system using the Network of Favors to reach the steady state, and showed that this time is approximately proportional to ρ, and that changing the proportion of peers that are free-riders has negligible effect on this time. In that study, however, we assumed that C was large enough to keep the system in famine. We now investigate the impact of C on the time needed for the system to reach steady state.

Figure 3 shows the proportion of the available resources that were donated to free-riders in the last 50 turns, which we denote ϵ. When the system is in famine, ϵ expresses how well the community has identified the free-riders. We found that C does not impact on the time needed for reaching the steady state, but on the actual value of ϵ that the system shows when in steady state. We found that, except for the scenarios where $\rho = 0.9$, ϵ is approximately inversely proportional to C. When $\rho = 0.9$, although ϵ is greater for $C = D/10$ than for $C = D$ and $C = 9D$, it is very similar in scenarios where peers have one of these two last eagerness levels. We suspect that in practice, when they have one of these two eagerness levels, the consumers act as eager consumers for the system. Thus, our observations show that eagerness makes it easier for the Network of favors to identify free-riders, although we have already found that eagerness is not a necessary condition for the system to work.

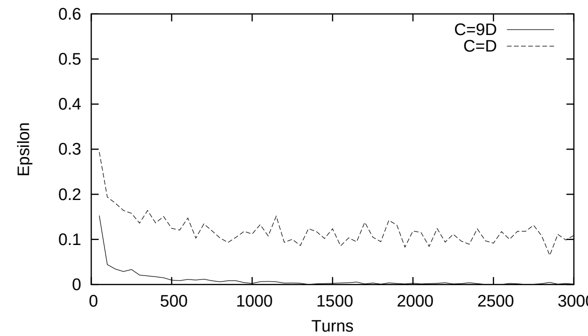

Figure 3. The proportion of resources donated to free-riders by the Network of Favors for $f = 0.5$, $\rho = 0.5$ and different values of C

5 Analysis of dynamic system behaviour

Now we consider the effect of allowing peers to change their strategies. The value of f_t will vary over time according to strategy choices, whereas the values of all other system parameters are fixed over time. We assume that peers change their strategy in their own best interest, choosing to be either a free-rider or a collaborator so as to maximize their expected utility. So the gradient of f_t is positive at t if the advantage to collaborators is negative at time t, and negative if the advantage to collaborators is positive at time t.

We do not need to offer peers a third option of leaving the system, because free-riders always have an expected utility at least as great as they would have outside the system. We assume that the choice of strategy is binary, that is, peers either choose to be a collaborator and offer all their spare resources to the community, or to be a free-rider and offer none: we do not consider the option of peers offering some but not all of their available resources.

We use an approximation similar to that used in Subsection 3.2, namely, we assume that we can determine the case (famine, middle or glut) for the system at time t, and whether the advantage to consumers is positive or negative, by calculating the case and the sign of the advantage to consumers for the expected values of x_d, x_c and x_f at that time. In practice statistical fluctuations may temporarily move the system into another case, but we assume that these excursions are sufficiently rare and short-lived that they can be ignored when we are considering the large-scale long-term dynamic behaviour of the system.

Figure 4 illustrates the dynamics of the system given these assumptions. The ratio of the mean values for x_d and x_c is independent of f_t, so is fixed over time. Therefore if famine holds for these mean values for the initial state of the system, it continues to hold for the subsequent evolution of the system. So if the system is initially in famine it should remain in famine as f_t decreases, (except for rare excursions given by statistical fluctuations), and eventually all the free-riders become collaborators.

If the system is initially in glut then f_t will increase until eventually the system is no longer in glut - at this point it will be in the middle case. At the border between the glut and middle cases free-riders have a higher expected utility than collaborators.

For the middle case, either the advantage to collaborators is negative for all $f_t \in (0, 1)$, in which case collaborators will eventually die out, at which point the system will not work, or else it is a monotonically increasing function of f_t for $f_t \in (0, 1)$ which tends to $-\infty$ as $f_t \to 0$ and to a positive number as $f_t \to 1$. For this second alternative the system will evolve to a stable equilibrium at which $f_t > 0$ and free-riders and collaborators have equal expected utilities. At the stable equilibrium the system does not work, because the advantage to collaborators is zero. (In practice the system may oscillate around the stable equilibrium rather than reaching it precisely, because of the statistical fluctuations in the value of resources donated and requested; but the average over time of the advantage to collaborators for the oscillating system will still be zero.)

It follows that if there is not a famine of donations, the proportion of free-riders will evolve over time to a value at which the system does not work. It is possible that the system initially is in a state in which it works, if the conditions for the middle case hold and the advantage to collaborators is positive, but it will eventually evolve to an equilibrium state in which the system does not work. This happens even though in this analysis we are assuming perfect identification of free-riders. On the other hand, if there is a famine of donations, then the system will work and free-riders will eventually die out.

This gives a relatively simple heuristic for checking

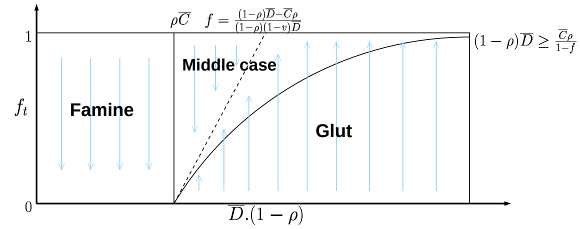

Figure 4. Dynamics of the system, varying f_t and $\overline{D}.(1-\rho)$.

if the system is eager enough for a reputation system to have a chance of acting to drive out free-riding by prioritizing donations to peers with high reputation: assuming that all peers choose to free-ride or not so as to maximize their expected utility, free-riding can only be driven out if there is a famine of donations, ie.

$$\overline{D}.(1-\rho) \leq \overline{C}.\rho \qquad (2)$$

Finally, we have verified the behavior of the Network of Favors in comparison to this prediction using our simulations. To do this, we introduced peers who choose their strategy based on the current advantage to collaborators in the system. To better gauge the prioritization of the Network of Favors, we let the peers change their strategies only after the system is in steady state.

When simulating our 54 sample scenarios, the Network of Favors managed to drive out free-riding for all the 30 scenarios where there was famine for donation, except for two. This two cases are (i) the border scenario for which our previous simulations showed that the Network of Favors does not have a positive advantage to collaborators ($C = 9D$, $v = 0.4$, $f = 0.25$ and $\rho = 0.1$) and (ii) a similar scenario, with the same C, v and ρ, but with $f = 0.75$. We suspect that the Network of Favors was not effective in the latter one because in this scenario a large number of free-riders change to to collaborating just after they start choosing their strategies. Note that these peers do not have any knowledge about the other peers in the community yet. Without this information, the prioritization of collaborators of the Network of Favors gets worse and the advantage to collaborators goes negative. The system then behaves very similarly to the scenario where $C = 9D$, $v = 0.4$, $f = 0.25$ and $\rho = 0.1$, making all other peers in the community decide to free-ride.

Nevertheless, in 28 out of the 30 scenarios considered, the dynamics of a system using the Network of Favors to drive out free-riding was similar to the predicted for an ideal reputation scheme.

6 Conclusion

In a previous paper [2] we showed that the Network of Favors autonomous reputation scheme is sufficient to discourage free-riding in a peer-to-peer resource sharing system where resources are interchangeable, provided that the peers are eager consumers. In this paper we have demonstrated by simulations that the Network of Favors is able to discourage free-riding when a strictly weaker requirement, that of a famine of donations, is satisfied. Our analysis of a system model indicates that when there is not a famine of donations, no reputation scheme should be able to discourage free-riding by prioritizing donations to peers with high reputations.

In our simulations of the Network of Favors for sample scenarios in which there was a famine of donations, there was an incentive for collaborating as opposed to being a free-rider in almost all scenarios where an ideal reputation scheme would also provide such an incentive. The cases where the results where different showed that the Network of Favors has a slightly worse prioritization than the ideal reputation scheme and therefore requires slightly more contention for resources to keep the utility of free-riders low. For the majority of the scenarios, both schemes performed similarly. The Network of Favors discourages free-riding by prioritizing donations almost as well as the ideal reputation scheme, despite being very lightweight and easy to implement, and requiring neither central coordination nor a cryptographic infrastructure.

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