Fairness in Peer-to-Peer Networks (Extended Abstract)

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1 Introduction

This work presents two different distributed resource allocation algorithms where peers control the service rate to its neighbours. The algorithms are based on the congestion pricing principle known from IP networks and ensure some form of fairness. Hence a peer gets a fair share of the resources available in the P2P network weighted by its contribution to the network.

2 Peer-to-Peer Model

Consider a P2P network consisting of a set of peers $\mathcal{P}$ and a set of services $\mathcal{S}$, whereby each peer p is interested in one or several services and/or offers different services. Thereby, providing a service consumes a scarce resource. We denote the capacity of this resource at peer p as C_p.
To differentiate between service providing and service requesting peers in our model we introduce the set of service providers $\mathcal{SP}$ and the set of service customers $\mathcal{SC}$. A peer is a member of $\mathcal{SP}$ or $\mathcal{SC}$ if it offers or requests at least one service, respectively. One peer can be a member of both sets, which is the predominant case in P2P networks.
Since each peer has only a partial view of the whole P2P network, a service requesting peer is not aware of all peers that provide this service, and vice versa. We define the set of peers, which offer at least one service to peer c, the service customer, as the set of service providers $\mathcal{SP}(c)$ of peer c. The other way around $\mathcal{SC}(p)$ is the set of the known service customers of the service providing peer p. Suppose the utility of a service customer c is defined by a concave, strictly increasing utility function U, which depends on the total service rate y_c. Similar to the rate control algorithm for IP networks we model the resource allocation

Dagstuhl Seminar Proceedings 06131
Peer-to-Peer-Systems and -Applications
http://drops.dagstuhl.de/opus/volltexte/2007/645

in P2P networks as the optimisation problem

$$\begin{aligned}
&\text{SYSTEM}: \\
&\quad \text{maximise} \sum_{c\in\mathcal{SC}} U_c(y_c) && (1)\\
&\quad \text{subject to} \sum_{p\in\mathcal{SP}(c)} x_{pc} = y_c,\ \forall c \in \mathcal{SC} && (2)\\
&\quad \sum_{c\in\mathcal{SC}(p)} x_{pc} \le C_p,\ \forall p \in \mathcal{SP} && (3)\\
&\quad \text{over} \quad x_{pc} \ge 0. && (4)
\end{aligned}$$

Maximising the aggregated utility of the service rate y_c over all service requesting peers is the objective of the whole system. With a concave utility function this optimisation problem has a unique optimum with respect to y_c, although many rate allocations may exist with respect to x_{pc}, the rate between peer p and c.

3 Distributed Algorithm

To realise an implementation in a decentralised architecture we propose the following system of differential equations, which depend on locally available information only:

RESOURCE PRICING (RP) :

Provider p :

$$\frac{d}{dt}x_{pc}(t) = \gamma x_{pc}(t)\left(\lambda_c(t) - \frac{\sum_{d\in\mathcal{SC}(p)} x_{pd}(t)\lambda_d(t)}{C_p}\right) \tag{5}$$

Customer c :

$$\lambda_c(t) = \frac{w_c}{y_c(t)} = \frac{w_c}{\sum_{p\in\mathcal{SP}(c)} x_{pc}(t)}, \tag{6}$$

Here, λ_c and w_c is the price per unit offered by customer c and the total willingness-to-pay of c. It can be shown that the stable point of the distributed algorithm coincides with the solution of the global optimisation problem [1]. The total service rate in equilibrium is

$$y_c = \frac{w_c \sum_{p\in\mathcal{SP}} C_p}{\sum_{d\in\mathcal{SC}} w_d}. \tag{7}$$

Hence, the optimal resource allocation is weighted fair.
If signalling of a price is not possible in the network, a peer can only adjusts its service rates based on the received service rates of the other peers. These rates can be interpreted as the total price a peer pays for a service rate. Therefore,

we can conclude the reciprocal rate control algorithm

$$\text{RECIPROCAL RATE CONTROL (RRC)}:$$
$$\text{Peer } p:$$
$$\frac{d}{dt}x_{pc}(t) = \gamma \left(x_{cp}(t) - x_{pc}(t) \frac{\sum_{d \in \mathcal{SC}(p)} x_{dp}(t)}{C_p} \right) \tag{8}$$

4 Simulation Results

We present first simulation results for the two proposed algorithms for file dissemination networks like BitTorrent. Thereby, resource pricing is interpreted as follows. A peer p acts as a service provider and a customer at the same time. It provides its upload capacity C_p to the network. Additionally, its upload capacity represents its contribution to the network. Therefore, the willingness-to-pay w_p is set to the upload capacity C_p. Each peer in the network adjusts its upload rates to other peers with the proposed algorithm and simultaneously signals its price offers to all peers it is interested in.
We compare the results of Resource Pricing (RP) and Reciprocal Rate Control (RRC) with BitTorrent's tit-for-tat (BT) strategy. When a new peer enters the network it connects to a random subset of N_R peers. Additionally, we assume all peers are interested in each other except itself.
An example is depicted in Fig. 1 for Reciprocal Rate Control with $N_R = 2$. Results about the weighted fairness index (WFI) and average download rate are shown in Fig. 2 and Fig. 3, respectively. Additionally, Table 1 summarises the results of the WFI for different scenarios. The results in the table are averaged over 10 runs, whereby the 95% confidence interval is ±0.003 at most. All simulations are run for 1000 peers entering the P2P network in the first second with a small time offset.

	BT	RP	RRC
$N_R = 2$	0.6	0.987	0.992
$N_R = 5$	0.857	0.997	0.992
$N_R = 10$	0.888	0.997	0.979

Table 1. Averaged WFI for different upload strategies

For the simulations with a varying number of peers we model the peer behaviour as a Poisson process, where the interarrival times between peers and the session times of peers are exponentially distributed. Also the results for varying peer populations in Fig. 4 and Table 2 indicate an improvement in fairness for the proposed algorithms as compared to the tit-for-tat strategy of BitTorrent. Thereby, Resource Pricing shows the best fairness lying near to the optimal allocation.
Further details about the proposed approach can be found in [1–3].

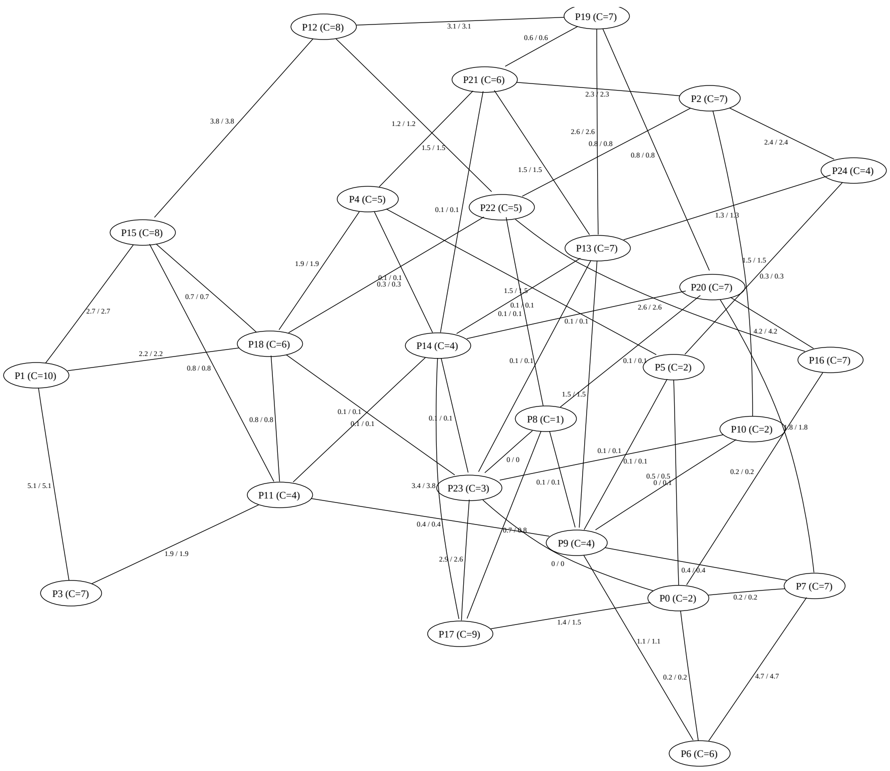

Fig. 1. Unstructured P2P network of peers with heterogeneous capacities. Edges denote a service between peers with a rate according to the edge label. Rates are computed with the distributed algorithm Reciprocal Rate Control.

	BT	RP	RRC
$\lambda = 1\,\mathrm{s}, \mu = 1000\,\mathrm{s}$	0.696	0.977	0.946
$\lambda = 10\,\mathrm{s}, \mu = 1000\,\mathrm{s}$	0.713	0.997	0.948

Table 2. Averaged WFI for varying peer populations ($N_R = 5$)

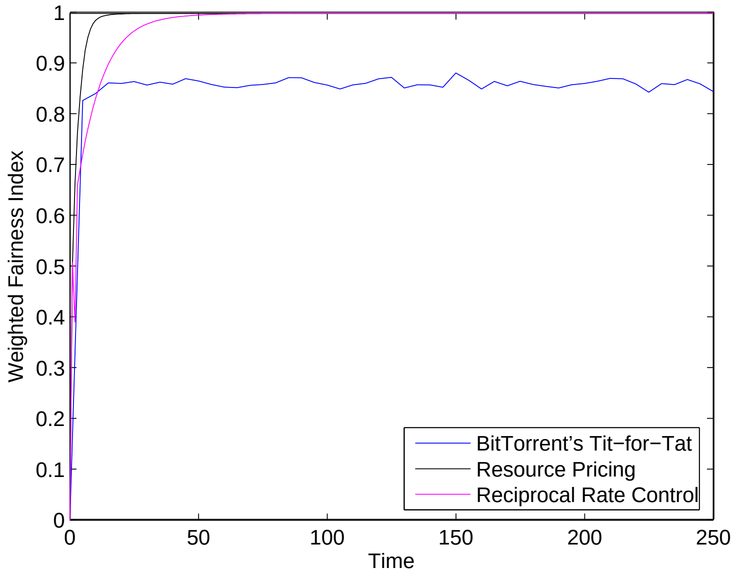

Fig. 2. Weighted Fairness Index of different upload strategies ($N_R = 5$)

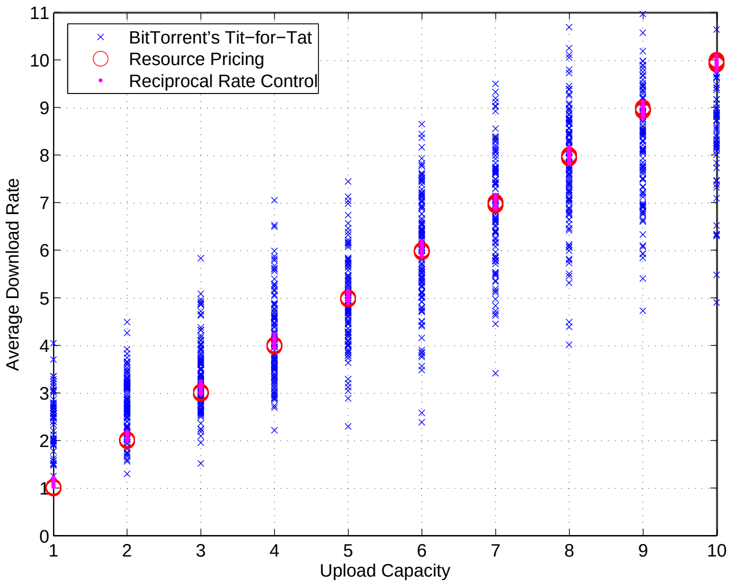

Fig. 3. Comparison of average download rate and upload capacity

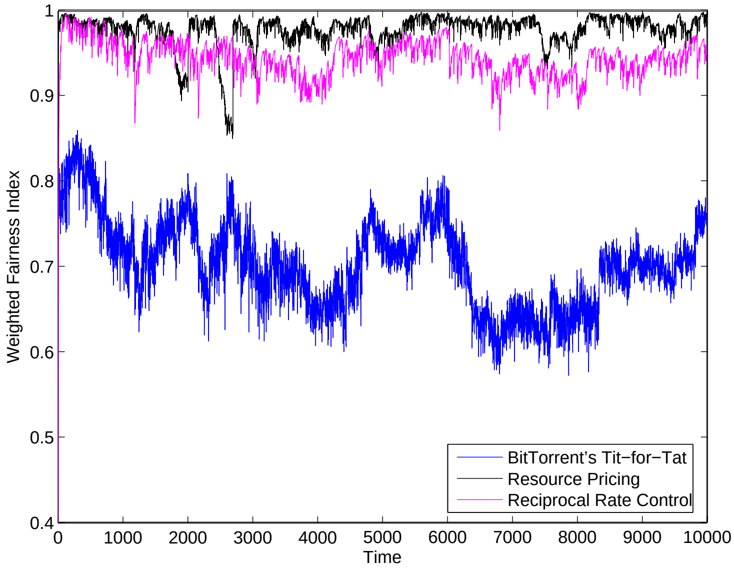

Fig. 4. WFI for a varying peer population ($\lambda = 1\,\mathrm{s}$, $\mu = 1000\,s$, $N_R = 5$)

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