The Use of Efficient Cost Allocation Mechanisms for Congestion Pricing in Data Networks with Priority Service Models ¹

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ABSTRACT

This paper demonstrates the application of two efficient cost allocation mechanisms on a simple FIFO network model in order to find congestion-based prices for network access services. It is shown that it is possible to obtain congestion-dependent prices in data networks (such as the Internet), establishing simultaneously different service quality levels among the users. The rationale behind these efficient distribution mechanisms is an axiomatic framework that determines a set of basic principles, highlighting the need for a fair allocation. Due to the characteristics of the price mechanisms and the possibilities of the parameter space in which these mechanisms might be applied, it is also shown that, in some cases, such mechanisms need additional weighting schemes in order to establish coherent differences among the service quality levels. In conclusion, even though the axiomatic framework guarantees efficient allocation, checking coherency in its use is left to the network manager.

Keywords: Aumann-Shapley pricing; data networks; efficient congestion-based pricing; non-pre-emptive priorities Shapley value

INTRODUCTION

Acknowledging the cost of congestion imposed by multiple users trying to get access to network services seems to be a promising path to a more efficient use of network resources. Applications with higher demand for resources such as multimedia applications coexist with more conventional less demanding applications, making it necessary to devise an economic solution to manage congestion in addition to the technical solutions already in place. In that direction, our work aims at quantifying the costs due to network congestion, making them explicit to the users in the form of prices.

Several influential articles appeared in the early 1990s (Cocchi et al., 1993; Mackie-Mason & Varian, 1995a; Shenker, 1995) that touched on the issue of designing pricing schemes for the Internet. Later on
there were extensions by Mackie-Mason & Varian (Mackie-Mason & Varian, 1995b) and the proposal for pricing according to expected capacity by Clark (Clark, 1998). A further step was given when priority was considered (Gupta et al., 1998), and the use of dynamic programming tools in congestion dependent prices was attempted (Paschalidis & Tsitsiklis, 2000).

The present article develops a pricing scheme based on a queuing model, extending the concepts originally worked on by McLean & Sharkey (McLean & Sharkey, 1994, 1997; McLean et al., 2004) for models with a first-in first-out (FIFO) discipline.

Our proposed model rests on the assumption that, under a centralized decision-maker acting on behalf of efficiency, the social cost imposed by the demands of users, which lead to congestion, must be acknowledged and dealt with in a fair manner. Such cost can be measured from the traffic characteristics of the different traffic sources. Recognition of the social cost imposed by others may act as a kind of tool to pricing congestion.

In our approach we turn our attention to existing cost-axiomatic methods that can assure the achievement of some desired properties of a cost-based pricing scheme. As Courcoubetis & Weber (2003) put it, “One necessary condition that cost-based prices ought to reasonably satisfy is that of fairness” (p. 164). One view of fairness follows cost causality; in that sense a cost-based pricing scheme should fully distribute costs while recognizing that users that impose the same effect on cost should have the same price.

Two relevant methods appearing in the literature in cost-axiomatic pricing are the Aumann-Shapley (A-S) prices and the Shapley value. These mechanisms are of interest because they fulfill a set of desirable properties, defined as axioms later on, and allow for the inclusion of heterogeneous users with different requirements, characterized by different value perceptions of information and network use.

A-S prices and the Shapley value are used to fully distribute the cost of congestion obtained as we use a queuing model of access service. Such access may well correspond to an Internet Service Provider, ISP, which serves two classes of users. The two-class approach serves to represent the further assumption that one class of users has service priority over the other. The users demand different services with different service characteristics, namely, the users’ arrivals rates and their service distribution rates. Using the average waiting time for a user type in the queue and the value to a user type of a service requirement, we define a congestion-based cost function. Such function is actually reflecting the loss due to the presence of multiple users trying to gain access to the provider.

We believe that embodying such desirable properties in axiomatic framework may help the designer of a pricing scheme understand how fairness in cost scheme due to congestion reflects on prices. As ISPs are growingly stressed to migrate from flat-fees to more flexible pricing schemes, considering the issue of fairness in a congestion-driven pricing scheme could be a tool to the efficient allocation of congestion costs. An additional component of the solution proposed is the possibility of reducing the strategic behaviour of users who attempt to manipulate the resource allocation to their advantage, for instance, in the context of auction-based allocation schemes. In a different but related context, axiom-based cost mechanisms have been considered in traffic-based cost allocation
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