Nash Bargaining in Bandwidth Allocation with appplications to mobile and satellite communications

Corinne Touati[◇,*], Eitan Altman[◇,*,†], Jérôme Galtier[◇,†,‡]

May 2001

Abstract

For over a decade, the Nash bargaining solution (NBS) concept from cooperative game theory has been used in networks as a concept that allows one to share resources fairly. Due to its many appealing properties, it has recently been used for assigning bandwidth in a general topology network between applications that have linear utilities. In this paper, we use this concept for the bandwidth allocation between applications with general concave utilities. We study the impact of concavity on the allocation and present computational methods for obtaining fair allocations in a general topology, based on a dual Lagrangian approach and on Semi-Definite Programming.

1 Introduction

Fair bandwidth assignment has been one of the important challenging areas of research and development in networks supporting elastic traffic. Indeed, Max-min fairness has been adopted by the ATM forum for the Available Bit Rate (ABR) service of ATM [1]. Although the max-min fairness has some optimality properties (Pareto optimality), it has been argued that it favors too much long connections and does not make efficient use of available bandwidth. In contrast, the concept of proportional fairness (of the throughput assignment) has been proposed by Kelly [6, 2], which gives rise to a more efficient solution in terms of network resources by providing more resources to shorter connections. An assignment is proportionally fair if any change in the distribution of the assigned rates would result in the sum of the proportional changes to be non-positive.

Although the object that is shared fairly seems to be a very specific one: the throughput, it is shown in [6, 2] that in fact, the starting point for obtaining (weighted) proportional fairness of the throughput can be a general (concave) utility function per connection; it is then shown that a global minimization of (weighted) sum of these utilities leads to a weighted proportional fair assignment of the throughput. As opposed to this approach, we wish to

[*◇]INRIA, 06902 Sophia-Antipolis Cedex, France. Email {ctouati,altman,jgaltier}@sophia.inria.fr
[†*]C.E.S.I.M.O., Universidad de Los Andes, Merida, Venezuela
[‡†] France Telecom R&D, 06921 Sophia-Antipolis, France

use a fairness concept which is defined directly in terms of the utilities of users rather than in terms of the throughputs they are assigned. Yet, as in weighted proportional fairness, it would be desirable to obtain this concept as the solution of a utility maximization problem, since it makes it possible to use recent algorithms for utility maximization in networks, along with decentralized implementations [5, 4, 7].

NBS is a natural framework that allows us to define and design fair assignment of bandwidth between applications with different concave utilities and has already been used in networking problems [8, 3]. It is characterized by a set of axioms that are appealing in defining fairness. As already recognized in [2] and later in [3], proportional fairness agrees with NBS in case that the object that is shared fairly is the throughput (and the minimum required rate is zero). We use NBS to study the fairness of an assignment where connection i has a concave utility over an interval $[MR_i, PR_i]$. It thus has a minimum rate requirement MR_i and does not need more than PR_i. Utility functions with similar features have been identified in [9] for representing some real time applications such as voice and video, and in the case that $MR_i = 0$, for elastic traffic.

We first study in this paper the way the concavity of the utilities affect the bandwidth assignment according to NBS, as well as according to a generalized version of the proportional fairness (in which the utilities that correspond to different assignments, instead of the throughputs, are fairly allocated). Both notions are introduced and their properties are studied. We then propose a quadratic approximation for the utility of each connection, which allows us to parameterize the degree of concavity of the utility function using a single parameter. We use this approximation to further analyze the impact of concavity of utilities on the resulting assignment. We present a Lagrangian approach which allows us to implement a decentralized protocol for the bandwidth allocation. We then present a novel alternative approach using Semi Definite Programming (SDP).

We conclude in describing some applications of fair bandwidth allocation to satellite and to mobile communications. In both cases, power, coding rate as well as the throughput can be controlled, with the aim of being efficient and fair.

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