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On Congestion Pricing in a Wireless Network *

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Abstract. The purpose of this paper is to study optimal pricing in a mobile distributed network with transmit power control. The paper proposes a linear congestion pricing scheme for the optimal distributed control of a wireless network. The optimal congestion price applies for the optimal resource control in a congested communication network where decisions on resource usage are made locally by the mobile nodes applying a learning automaton. Numerical examples for the convergence of a price controlled wireless network to a Pareto-optimal transmit power allocation are presented.

Keywords: pricing, congestion control, power control

1. Introduction

Modern communication networks present new challenges to radio resource management. One such area in resource management is congestion control due to limited bandwidth being shared by mobile nodes with increasing demands for heterogeneous services. The design and control of such self-organizing complex communication systems presents new multidisciplinary challenges of economic, engineering and mathematical nature [18]. The purpose of this paper is to study resource management, in terms of the allocation of transmit powers, in a mobile distributed network from the point of view of complex systems theory.

Complex systems theory is a multidisciplinary theory concerned with self-organizing distributed systems. Wireless ad hoc networks are examples of self-organizing distributed systems; in these networks the mobile nodes need not always be directly connected to a base station [5,20]. The key characteristic of resource allocation in a distributed wireless system is that each user is allowed to decide on the level resource demand, instead of a base station stipulating a centrally optimal transmit power allocation. In a distributed communication network the quality of service is a macroscopic feature arising from the microscopic behavior of the users deciding on resource usage.

Following [16], a distributed network such as the Internet with pricing is one where the users of the network maximize their utility functions and the network service providers maximize revenue from providing services. Recently it has been shown that there are prices under which a rate allocation in a distributed system is Pareto-efficient [16,18]. The current paper focuses on studying the conditions for the decomposition to hold in the case of a power controlled wireless network. First, concavity conditions for the utility function of the users are assumed, like in [16]. Secondly, congestion based pricing is introduced to account for the resource shadow prices (cf. [11]) in a congested wireless network.

A distributed system can be analyzed using noncooperative game theory. Following [26], the game-theoretical approach allows to describe the network as a noncooperative system with emphasis on modeling individual incentives. This paper addresses the issue of the economics/resource allocation in a distributed wireless network. Previously, resource allocation in a wireless network has been studied from economics/game theory point of view in [8,11,13–15,19,25] and the economics of the Internet has been discussed, e.g., in [3,22].

The resource demands from other users often impose a congestion externality cost, which appears as an increased delay or as a deteriorated signal-to-noise ratio due to limited bandwidth [3,9]. Congestion can be a problem for example in ad hoc wireless networks where the network topology changes fast and where the resource allocation is distributed in nature. This paper elaborates [9,10] to argue for the optimality of congestion based pricing in an interference-limited wireless network. This is analogous to the concept proposed independently in [25] for utility-based power control in a wireless system; the difference between the current paper and [25] is the congestion measure to which the price should be related.

The framework for analysis is the signal-to-noise model of the uplink of a single-cell wireless network due to [28], extended to the economics of the network. Control mechanisms other than power control, such as handoff, coding or modulation are not considered.

The paper is organized as follows. Section 2 discusses a Pareto-optimal solution to the transmit power allocation problem in a wireless network. Distributed discrete resource allocation is discussed in section 3 from the point of view of transmit power control in a third generation wireless system. Section 4 presents a noncooperative game model of a distributed solution to transmit power allocation. Section 5 discusses distributed resource allocation under congestion pricing. Section 6 presents numerical examples of distributed transmit power allocation applying a discrete distributed algorithm.

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