DISTRIBUTED RATE OPTIMIZATION IN AD HOC NETWORKS WITH RANDOM ACCESS

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ABSTRACT

This work focuses on designing distributed rate control algorithms for competing end users in a wireless ad hoc network. The goal is to use the scarce bandwidth resource efficiently while ensuring fairness amongst end users at the same time.

Rate optimization problems in wireless ad hoc networks are fundamentally different from and much more difficult than their counterparts in wireline networks. While links in a wireline network typically have fixed quantities, this is not true in wireless ad hoc networks. Instead, links in a wireless network are broadcasting in nature, and a MAC (Medium Access Control) protocol is often adopted to reduce collisions and to ensure high system throughput. For this reason, link capacities in a wireless network are not fixed quantities, and are typically functions of the parameters of the MAC protocols, like transmission probabilities and back-off window sizes. Therefore rate optimization in a wireless network must be considered in conjunction with MAC protocols, and we restrict our consideration to the class of wireless ad hoc networks with random access.

In this work, we first consider the problem of max-min fair rate allocation in a random access network. Two different flavors of max-min fairness are considered. The first one is called simple max-min fairness, whose objective is only to maximize the minimum rate in the network. Although the simple max-min fairness problem is formulated as a non-convex and non-separable program, we use a transformation to convert it to a separable convex program and propose two distributed algorithms to solve it in an iterative manner. We then proceed to consider the widely used max-min fairness criteria, in which minimum link rates are maximized in a lexicographic order. This is intrinsically a multi-criteria optimization problem. Exploring the connection between the simple and lexicographic max-min fairness, we propose two iterative approaches that attain the optimal rates under very general assumptions on the network topology and the communication pattern. It is interesting to note that our approaches are amenable to distributed implementations, and nicely connect to the “bottleneck-based” lexicographic rate optimization algorithm popularly used in

wired networks [1].

In the second part of our work, we consider providing proportional fairness for end-to-end sessions in a wireless ad hoc network with a general topology. Specifically, we address the problem of how to introduce a cooperation between the link layer and the transport layer so that aggregate utilities of all end-to-end sessions are maximized. Two algorithms are proposed to solve the problem in a distributed manner. Analytical and simulation results are provided to show that both algorithms converge to the globally optimum.

In the third part of our work, we consider fair resource allocation problems in a CSMA/CA based wireless ad hoc network. We propose a throughput model for the CSMA/CA network with a general topology. Based on the model, we can well interpret the unfairness originated from the "hidden node problem" and the trade-off between throughput and fairness. Although our throughput model needs topology information of the entire network, we show how it can be approximated using only local topology information. The performance of the approximation is investigated with both analysis and simulation. Three distributed scheduling methods, based on the throughput approximation, are then proposed to provide fairness among the contending users, and their performances are compared based on simulation studies.

In the last part of our work, we consider rate optimization in a wired-cum-wireless network, where CSMA/CA based wireless LANs extend a wired backbone and provide access to mobile users. The objective is to achieve proportional fairness amongst the end-to-end sessions in the network. A dual-based algorithm is proposed accordingly. This algorithm works in a distributed manner, and converges to the global optimum. Simulation results are presented to support our analysis.