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Framework for Delay Analysis of Channel-aware Wireless Schedulers

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Abstract

We consider the scheduling problem over wireless channels for real-time applications where the Quality of Service requirements are given in terms of delay statistics. Although many wireless channel-state dependent (CSD) schedulers have been proposed recently, their contributions lie in the design of the scheduling mechanism to meet some performance objectives. However, the delay performance are specified in terms of first-order statistics, i.e., average or worst-case values, which are insufficient to characterize the scheduler's performance.

In this paper, we develop a framework for the stochastic analysis of the delay performance of CSD schedulers. We derive the delay probability density function and its moments for a Two-State Markov Chain Error Model using a matrix formulation approach. We demonstrate the applicability of our analysis numerically by considering the admissibility of a wireless scheduler in terms of a minimum throughput requirement. This translates to an upper bound on the mean Head-of-Line (HOL) packet delay. Subsequently, we evaluate the buffer size requirement of the wireless receiver and highlight the trade-off between buffer size requirements and channel efficiency.

I. Introduction

A. Related work in Wireless Scheduling

An abundance of scheduling policies that provide guaranteed Quality of Service (QoS) for wireline networks exists in the literature ([1], [2], [3], to name a few). However, direct application of these policies to the wireless media is not useful due to the following unique characteristics: (a) high channel error rate (b) bursty and time-varying channel capacity (c) location dependent channel capacity (d) user mobility and (e) power constraint of mobile users.

The notion of channel-state dependence (CSD) or awareness was introduced in [4] to improve the performance of wireline schedulers when deployed in a wireless media by exploiting characteristics (b) and (c). [5] offers a comprehensive survey of variants of CSD schedulers that differ in the mechanism of choosing the instantaneous 'best' flow to transmit while satisfying different constraints. Such constraints can often be specified in terms of the long-term fraction of time to be allocated to each user (time-fraction requirement).

In [6], the authors defined the scheduling problem as one of maximizing the average system performance. An opportunistic (equivalent to channel-state aware) scheduling policy is proposed that solves the scheduling problem optimally. In addition, the algorithm also improves every user's average performance relative to any non-opportunistic scheduling policy and also takes into account the short-term performance requirements of users. However, it is unclear how the scheme performs in terms of per-flow QoS when handling delay-sensitive traffic.

The concept of 'compensation' was introduced and employed in CSD schedulers proposed in [7], [8], [9], [10], [11], [12] to achieve a tradeoff between channel efficiency and short-term fairness provision. While wireline scheduling is used under error-free conditions, a wireless adaptation scheme is employed when these conditions no longer prevail. Essentially, flow swapping takes place when an allocated flow is unable to transmit in order to maximize channel efficiency. Flows that 'gave up' their allocated slots are subsequently compensated by flows that 'acquired' those additional slots so as to maintain short-term fairness. The performance of these schedulers in terms of throughput, delay and fairness was analyzed and compared in [13].

B. Research Contributions of This Paper

In this paper, we consider the scheduling problem for real-time applications (e.g., streaming and interactive audio/video) whose QoS requirements can be specified in terms of delay statistics. Many wireless schedulers have been proposed in the literature recently whose main contributions lie in the design of the scheduling mechanism to meet various performance objectives. Although delay analysis has been performed for the proposed schedulers, the metrics used are first order, i.e., average and worst-case values, which are inadequate to characterize the scheduler's performance. For example, the receiver buffer requirement depends on both the mean as well as the variance of the inter-arrival time (i.e. the HOL packet delay of the scheduler).

Our focus is to propose a framework for stochastic analysis of the delay performance of CSD schedulers. Our approach is similar to that adopted in [14], where the authors studied the delay performance of a simple ARQ error control strategy for