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Downlink data transmission scheduling algorithms in wireless networks

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ABSTRACT

The problem of downlink data transmission scheduling in wireless networks is studied. It is pointed out that every downlink data transmission scheduling algorithm must have two components to solve the two subproblems of power assignment and transmission scheduling. Two types of downlink data transmission scheduling algorithms are proposed. In the first type, power assignment is performed before transmission scheduling. In the second type, power assignment is performed after transmission scheduling. The performance of two algorithms of the first type which use the equal power allocation method are analyzed. It is shown that both algorithms exhibit excellent worst-case performance and asymptotically optimal average-case performance under the condition that the total transmission power is equally allocated to the channels. In general, both algorithms exhibit excellent average-case performance. It is demonstrated that two algorithms of the second type perform better than the two algorithms of the first type due to the equal time power allocation method. Furthermore, the performance of our algorithms are very close to the optimal and the room for further performance improvement is very limited. It is shown that all the above algorithms can be extended to schedule downlink data transmissions with parallel channels. It is also shown that the simple sequential scheduling algorithm is optimal if the total transmission power is equally allocated to the channels. As an extra contribution, an M/G/1 queueing model for the FCFS queueing discipline is established, and it is observed that increasing the number of channels has more impact on the reduction of the average response time than increasing the total transmission power.

1. Introduction

1.1. Motivation

The new generation (3G and beyond) wireless networks provide multiple channels (such as codes, frequency tones, and time slots) through code division multiple access (CDMA), wideband orthogonal frequency division multiplexing (OFDM), and multislot time division multiple access (TDMA). These channels can be allocated to users with different transmission powers and rates. These advancements provide more flexibility in network traffic control and raise new interesting power and channel allocation and data transmission scheduling problems [2,3,11,14,16].

In a wireless network, there is a base station in each cell. The base station handles all requests of data transmission to (downlink) and from (uplink) mobile users in the same cell. It is expected that in emerging wireless networks, data traffic has asymmetrically large downlink demand. Given certain amount of transmission power and certain number of communication channels, and a set of downlink data transmission requests, the downlink data transmission scheduling problem is to

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find a power assignment to the transmission requests and a nonpreemptive schedule of the transmission requests, such that the total time to complete the set of data transmissions is minimized (see Section 2 for a more accurate definition of the problem).

Since both transmission power and communication channels are critical resources in wireless networks, it is an important research problem to find and develop power assignment and transmission scheduling algorithms to effectively and efficiently utilize transmission power and communication channels and to reduce the data transmission times. Unfortunately, there has been little such study in the literature. The motivation of this paper is to investigate heuristic algorithms for downlink data transmission scheduling in wireless networks. To the best of the author's knowledge, this is the first attempt to study nonpreemptive downlink data transmission scheduling algorithms.

1.2. Summary of contributions

It is clear that the downlink data transmission scheduling problem contains two subproblems, namely, *power assignment* and *transmission scheduling*. Hence, every downlink data transmission scheduling algorithm must have two components to solve the two subproblems. In this paper, we consider two types of downlink data transmission scheduling algorithms, depending on which subproblem is solved first. The name of an algorithm is represented as *X*–*Y*, where *X* is the strategy for power assignment and *Y* is the strategy for transmission scheduling.

In the first type, power assignment is performed before transmission scheduling. In our algorithms, the total transmission power *P* is equally allocated to the channels, i.e., data transmissions are scheduled with *equal powers* (*EP*). We examine the performance of algorithms *EP-LS* and *EP-LPT* which use the well known online *list scheduling* (*LS*) and the offline *longest processing time* (*LPT*) algorithms to schedule downlink data transmissions in wireless networks. It is shown in Sections 3–5 that both algorithms exhibit excellent worst-case performance and asymptotically optimal average-case performance under the condition that the total transmission power is equally allocated to the channels. In general, both algorithms exhibit excellent average-case performance.

In the second type of downlink data transmission scheduling algorithms, power assignment is performed after transmission scheduling. First, data transmissions are scheduled using *virtual times* which give certain measure of actual transmission times. Then, the total transmission power *P* is allocated to the channels such that all the channels complete their data transmissions at the same time. We demonstrate in Section 6 that algorithms *ET-LS* and *ET-LPT*, which schedule data transmissions using algorithms *LS* and *LPT* and assign powers to achieve *equal times* (*ET*), perform better than algorithms *EP-LS* and *EP-LPT*.

Since the preliminary version of the paper [13] was presented, we have extended our work by considering downlink data transmission scheduling with parallel channels. We show that by using the equal channel allocation method, all the above algorithms can be extended to schedule downlink data transmissions with parallel channels and improved performance can be obtained in Section 7. We also show that when parallel channels can be allocated to data transmission requests, the simple sequential scheduling algorithm is optimal if the total transmission power is equally allocated to the channels. As an extra contribution, we establish an M/G/1 queueing model for the first-come-first-served (FCFS) queueing discipline and observe that increasing the number of channels has more impact on the reduction of the average response time than increasing the total transmission power.

2. Preliminaries

2.1. The data transmission model

Assume that the base station has total transmission power *P*. There are *C* wireless channels. The power *P* can be divided and allocated to the channels.

We adopt the channel specifications similar to the original 3G system proposals [3,4,15] for our data transmission model. Each communication channel is characterized by the *signal to interference plus noise ratio* (*SINR*) [8] given by

$$SINR = \frac{gp}{\sigma^2}.$$

In the above equation, p is the power assigned to the channel and σ^2 is the total noise power including interference. Power attenuation of a channel is specified by the parameter

$$g = \frac{S}{d^\alpha},$$

called the physical gain, which is determined by the shadow loss component S, the distance d between a mobile user and the base station, and the distance loss exponent α.

The transmission rate (in bits per second) of a channel is given by the following equation:

$$r = W\log_2\left(1 + \frac{SINR}{\Gamma}\right),$$