FAST PACKET SCHEDULING ASSURING FAIRNESS AND QUALITY OF SERVICE IN HSDPA

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Abstract

We consider packet scheduling in High Speed Downlink Packet Access (HSDPA) networks in the presence of heterogeneous channels. In this case, Proportional Fairness (PF) scheduling and its enhanced version, the Data Rate Control (DRC) Exponent rule, fail to achieve the goal of providing fair data rates to the users. We propose in this paper a scheduling policy that resolves this problem. The proposed Adaptive Proportional Fairness (APF) scheduling is shown to ensure proportional fairness even for users experiencing different channel conditions. The APF algorithm is subdivided in two modules: a short-term module which consists of an enhanced version of the selection criterion adopted in the DRC Exponential rule, and a long-term monitoring module, in which we make updating of the control parameters that we introduce to ensure fairness among users. Simulation results and comparisons, provided for the Best-effort mode of operation, show the high efficiency of our approach compared to Proportional Fairness scheduling.

Keywords: *Resource allocation, packet scheduling, Proportional Fairness, HSDPA.*

1. INTRODUCTION

Channels in wireless networks are characterized by their fast and random variations in time making it a challenge to ensure fairness among users with different channel conditions. Fast packet scheduling is the main component of High Speed Downlink Packet Access (HSDPA) [1] that aims at tracking the variations of the channels. In each Transmission Time Interval (TTI), the scheduler's objective is to select the user or users for which packets would be transmitted depending on their Modulation and channel Coding Schemes (MCS) for the purpose of increasing the system's performance both in terms of throughput and fairness. One of the known algorithms that attempts to achieve a reasonable throughput-fairness tradeoff is the Proportional Fairness (PF) algorithm [2], which is implemented in HDR (High Data Rate) [3] networks. However, recent studies [4], [5], [6] based on this algorithm showed unevenness in the data rates achieved by the different users when these experience different channel conditions in terms of the corresponding fading properties. Indeed, with PF scheduling, the user whose channel exhibits the highest variance gets privileged over the other users, which yields unfairness in the service of communicating users. Nevertheless, the PF method has some properties which are useful if applied to packet scheduling in HSDPA. In fact, after a certain time, the PF method converges to a steady state, represented by the average data rate allocated to each user. In HSDPA, the TTI is equal to 2ms, which is very small compared to the duration of 10, 20, 40 or 80ms, as specified in the WCDMA Release'99 architecture [7]. This short TTI makes the time of convergence acceptable and allows to perform more processing, in a short time, in order to countermeasure the PF problem and provide fair data rate to the users.

One of the proposed solution to the PF unfairness problem, is the modified PF algorithm which is also called the Data Rate Control (DRC) Exponent rule [6]. However, even with this algorithm, fairness is not guaranteed at all time but only for some specific cases. In this paper, we propose a new scheduling algorithm, called Adaptive Proportional Fairness (APF), that resolves the PF unfairness problem in heterogeneous channels. Specifically, we add to the user selection criterion, an updating module, which tracks the data rate allocated to each user and updates the exponent parameters in order to achieve fairness among the different users based on the quality of their channels. Unlike the DRC Exponent rule [6], herein we use for each user an exponent parameter, into having the possibility of changing the proportional data rate for a user without changing the share of the other users.

The remainder of this paper is organized as follows. In Section 2, we briefly review the importance of scheduling

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CCECE 2004 - CCGEI 2004, Niagara Falls, May/mai 2004
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in HSDPA and highlight the principle of the Proportional Fairness method and its drawback. Section 3 presents the proposed APF algorithm. In Section 4, we provide the different channel models used in our performance evaluation and present comparisons of the results provided for the PF and APF algorithms. Conclusions are drawn in Section 5.

2. SCHEDULING IN HSDPA AND THE PROPORTIONAL FAIRNESS POLICY

2.1 Scheduling in HSDPA Networks

Compared to the Release'99 architecture [7], HSDPA introduces a short 2ms TTI, adaptive modulation and coding (AMC), multicode transmission and fast physical layer (L1) hybrid ARQ (H-ARQ). In addition, the packet scheduler is moved from the radio network controller (RNC) to the Node-B, where it has easy access to air interface measurements, making it possible to match the data rate to the radio channel conditions. In HSDPA Release'5 [1], the user equipment periodically sends a Channel Quality Indicator (CQI) to the Node-B to indicate the data rate that the user equipment can support under its current radio conditions. In HSDPA Release'6 [8], there is introduction of an enhanced CQI reporting method sent every positive acknowledgement (ACK) or negative acknowledgement (NACK), or with NACKs only. This enhancement was introduced to make up-to-date CQI information available to the Node-B for future transmissions to the users. In a recent Working Group [9], it was also proposed to map the twenty one CQI values to a list of data rates to be used by the scheduler. This mapping supposes that the user can bear a maximum of five simultaneous codes.

2.2 Proportional Fairness Scheduling

In the Proportional Fairness (PF) method [2], the user selection criterion is given by

$$j = \arg \max_{1 \leq i \leq N} \frac{r_i}{R_i}, \tag{1}$$

where j is the index of the selected user for the next TTI, N is the total number of users, r_i is the instantaneous data rate the user equipment i can support under its current channel conditions, and R_i is the average achieved rate defined as the average data rate effectively received by user i. These rates are updated, at each TTI, according to the following rule:

$$\begin{cases} R_j = (1-\alpha)R_j + \alpha r_j & \\ R_i = (1-\alpha)R_i & \text{if } i \neq j \end{cases} \tag{2}$$

where α is a smoothing parameter with $0 < \alpha < 1$.
The PF policy gives fair allocation of data rates between users when these experience similar channel conditions. In real systems, due to the different fading properties the users' channels experience, the PF algorithm fails in allocating fair data rate to users that is proportional to their mean rate. Indeed, it was shown in [4], [6], that the user with more channel variability gets privileged over the other users and receives a higher data rate. In order to provide fairness between users depending only on their average data channel rate ($\overline{r}$), a solution to the problem was proposed in [6] where by adding an exponent term to r_i, which indicates the channel condition in the PF policy (1), the so-called DRC Exponent rule allows to control the allocated time to the users with better channel quality compared to the ones with bad channel conditions. In the DRC Exponent method, the selection criteria is given by:

$$j = \arg \max_{1 \leq i \leq N} \frac{{r_i}^n}{R_i}, \tag{3}$$

where n is the exponent parameter, introduced to manage the relationship between the data rates (R_i) of the users with different channel conditions. However, the control parameter n taking a fixed value for all users, two problems arise with this approach. First, the control parameter being fixed in time, it does not adapt to the current radio conditions of each user. Second, as this parameter takes a unique value for all users, it is not possible to fix a value for n that ensures fairness between all users at the same time.

In the following, we present our solution to the problem and describe the Adaptive Proportional Fairness scheduling algorithm which is studied in the scenario where no rate constraints are considered and the algorithm operates in the *Best effort* mode.

3. ADAPTIVE PROPORTIONAL FAIRNESS SCHEDULING

In the *Best effort* mode, the issue is to maximize the total data rate while providing for fairness among the communicating users. The user selection criterion is given by

$$j = \arg \max_{1 \leq i \leq N} \frac{{r_i}^{c_i}}{R_i}, \tag{4}$$

where c_i is the control parameter corresponding to user i. The Adaptive Proportional Fairness (APF) user selection criterion can hence be seen as an enhancement of the DRC Exponent rule where an independent control parameter is assigned to each user in order to avoid the dependency between the different users. However, to be able to track the fast variations of the channels and the differences between the channels of the different users, we add a monitoring module which updates the values of c_i, $i = 1, \ldots, N$, for the purpose of satisfying the equality between the proportional allocated data rate values ($\frac{R_i}{\overline{r}_i}$). The scheduling is executed at each TTI whereas the updating is performed at a larger timescale. This is to ensure that the algorithm has a chance to function properly to make good decisions about the allocated data rates (R_i), and to correct it only when necessary for purpose of achieving proportional fairness between the users. Herein, the updating is made every $50 * TTI = 0.1s$. In the updating module, we verify whether the difference between the proportional data rate allocated to user i, $\frac{R_i}{\overline{r}_i}$, and the average value over all users, is within acceptable values defined by the interval $[-\varepsilon, \varepsilon]$. If the condition is not satisfied, the control parameter c_i corresponding to the user under consideration is updated, along with the parameters of the other users. The updating of c_i, $i = 1, \cdots, N$, is performed according to the following rule:

$$\begin{cases} c_i = c_i + \Delta c & \text{if } (\frac{R_i}{\overline{r}_i} - \frac{1}{N}\sum_{j=1}^{N}\frac{R_j}{\overline{r}_j}) < -\varepsilon \\ c_i = c_i - \Delta c & \text{if } (\frac{R_i}{\overline{r}_i} - \frac{1}{N}\sum_{j=1}^{N}\frac{R_j}{\overline{r}_j}) > \varepsilon \end{cases} \qquad (5)$$

where the choice of Δc depends on the speed of convergence sought and the desired strength of variations around the value at convergence. By increasing the value of Δc, faster convergence to the steady state of R_i is reached but with more oscillations around this value. In order to avoid these oscillations around the average effective data rate values at convergence, we fix in our simulations Δc at 0.01. As for the average smoothing parameter α, we consider a value of 0.001.

4. NUMERICAL RESULTS AND DISCUSSIONS

In this section, we present simulation results and comparisons of the Proportional Fairness method and the Adaptive Proportional Fairness algorithm. We consider eight communicating users and suppose that only one user is selected in each TTI. In HSDPA, more than one user can be selected. This can be performed by our algorithm through ordering of the active users, selection of the first user, and verification of the availability of resources, namely, codes remaining out of the 16 available codes, that could be allocated to more users while satisfying the power budget constraint. In this way, time multiplexing is privileged over code multiplexing. Indeed, in [10], it was shown that time multiplexing, where it is preferable to transmit to few users but at their full available rates, yields higher performance compared to code multiplexing. Without loss of generality, we also assume that all rates are feasible. The continuous assumption versus the discrete case of study does not affect the conclusions, drawn herein, given that the APF algorithm is compared to the PF technique under the same operating conditions. In addition, as specified in [9], we can choose between twenty one data rate values, which keeps the allocation error for the continuous case at a minimum.

For each user, we suppose that the air data rate is proportional to the quality of the channel [4], [6]. For example, if the user exhibits Rayleigh fading, the power of the received signal will be exponentially distributed, and so would his instantaneous data rate r_i be. We consider a general formulation of the user air data rate r_i, namely, $r_i = R_{i_0} * Y * 10^{\frac{X}{10}}$, where R_{i_0} represents the data rate value when user i has a constant air data rate, Y models the fast fading component, modelled as an exponential distribution, and X refers to the shadowing variable (in dB) following a Gaussian distribution with mean equal to 0dB. In Table I, we provide the values used in our simulations. As shown, different combinations of propagation channels are considered in order to generalize our analysis and performance evaluation.

TABLE I

SUMMARY OF AIR DATA RATE DISTRIBUTION PARAMETERS FOR THE DIFFERENT USERS

	Rayleigh (mean)	Shadowing (standard deviation)	R_{i_0}
User 1	-	-	80 Kb/s
User 2	-	-	80 Kb/s
User 3	-	4 dB	80 Kb/s
User 4	-	6 dB	80 Kb/s
User 5	-	8 dB	80 Kb/s
User 6	80 Kb/s	4 dB	-
User 7	80 Kb/s	6 dB	-
User 8	80 Kb/s	8 dB	-

We represent in Figure 1 the average data rate R_i, achieved by each user, as a function of time when using the PF algorithm. As observed, even if the users have the same mean data rate $\overline{r}_i$ (Table I), available on their own channel, the PF method does not allocate the data rates fairly among the users. This is due to the difference in the variations exhibited by the channels of the different users, namely, the difference in the variance associated to each channel distribution. The more the channel variation is, the higher is the average data rate R_i allocated to the corresponding user.

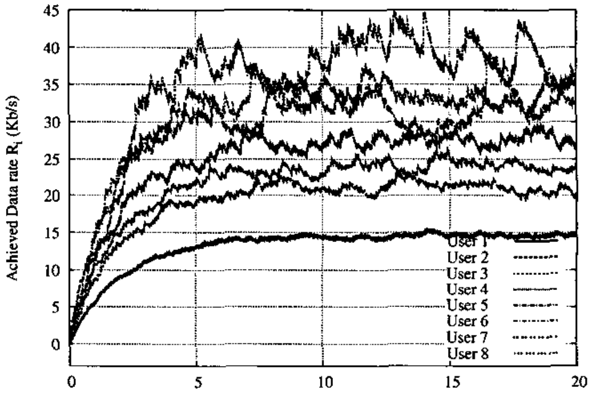

Fig. 1. Evolution of data rates R_i with time using the PF method (curves are represented in a descending order, the upper curve corresponds to user8, and the one at the bottom to user1)

Comparing these results with the ones obtained using the APF algorithm (Figure 2) shows how our algorithm outperforms the PF method by fairly allocating the data rates despite the differences in the channel distributions of the different users or the underlying variances. This can be observed in Figure 3 comparing the proportional allocated data rate for the PF method and the APF algorithm. For example, we can see that the PF allocates for user8 46% of his air data rate whereas user1 gets allocated only 18% of the data rate his channel can support, a value that represents less than half the share corresponding to user8. On the other hand, using the APF algorithm, the allocation is between 26% and 28% for all users. However, and as expected, this improvement in fairness comes at the cost of a reduction in the total data rate ($\sum_{i=1}^{N} R_i$). Indeed, as can be seen in Figure 4, the APF algorithm results in a loss of $20kb/s$ in total data rate, which represents 10% of the total allocated

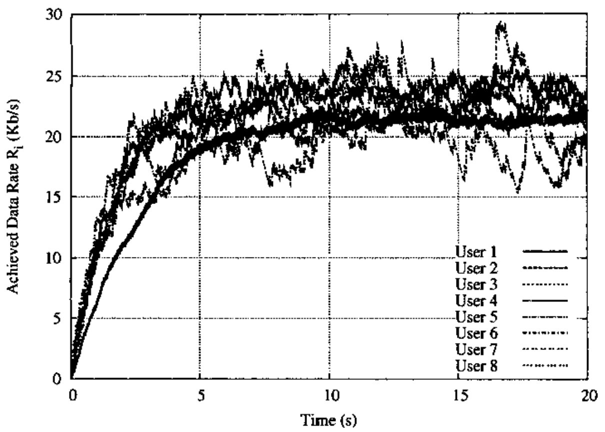

Fig. 2. Evolution of the average data rates R_i with time using Adaptive Proportional Fairness scheduling

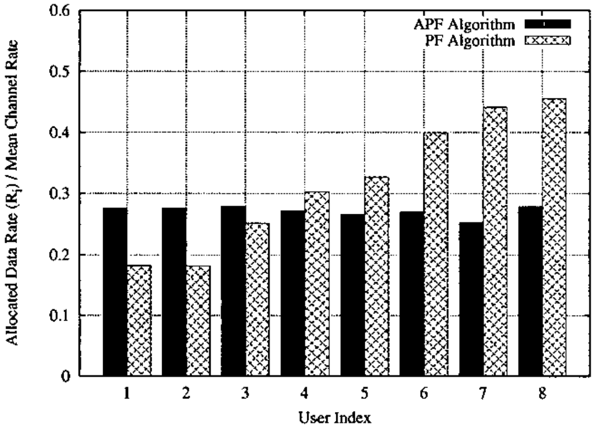

Fig. 3. Comparison of the proportional allocated data rate $\frac{R_i}{\overline{r}_i}$ for the PF and APF algorithms

rate using the PF algorithm, and corresponds to 3% of the sum of the average data rates ($\overline{r}_i$) available on the users channels ($8 * 80kb/s$). Consequently, compared to the PF policy, the APF algorithm achieves the required fairness between users with heterogeneous channels at no significant loss in total data rate.

5. CONCLUSIONS

This paper proposed a new fast packet-scheduling algorithm, the Adaptive Proportional Fairness (APF) scheduling, which resolves the DRC Exponent rule problem in failing to achieve fairness between users in heterogeneous channels. By adding a user control parameter in the criterion used to select the user to transmit to, and introducing an updating module to track the fast variations of the channels, the APF algorithm was shown to provide the required fairness between users. We considered heterogeneous propagating conditions experienced by the communicating users and investigated the APF performance under *Best effort* service. APF scheduling was shown to outperform the Proportional Fairness method, in terms of fairness that it yields between users at no significant loss in total data rate. Under investigation is the implementation of the APF algorithm under QoS constraints, discrete rates and Automatic Repeat Request (ARQ) retransmission.

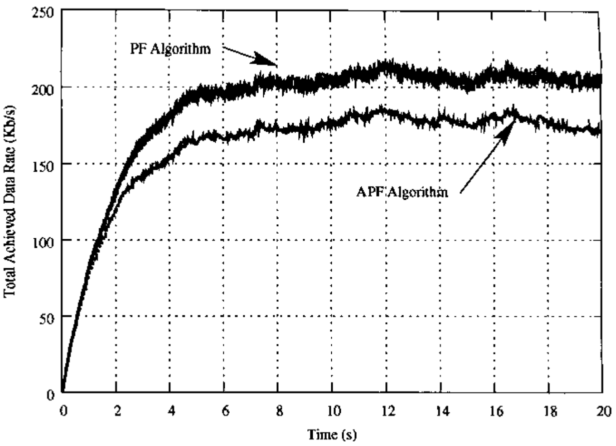

Fig. 4. Evolution of the total achieved data rate by all users: comparison between the PF and APF algorithms

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