Transmission Scheduling Algorithm with Cell Loading Control in a DS/CDMA Cellular System

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ABSTRACT

Maintaining a proper level of cell load, system throughput can be maximized by a transmission rate control over the uplink in DS/CDMA cellular system to support integrated services of real-time and delay-tolerant traffic. We find that the cell load-based rate control scheme can be further enhanced by taking the varying channel condition into account in conjunction with some fair scheduling algorithm. Our simulation results show that the proposed scheme outperforms the original cell load-based rate control with the round-robin sharing scheduling scheme.

I. Introduction

Emerging requirements for higher rate packet data services and better spectrum efficiency are the main issues of third-generation mobile radio systems with DS/CDMA air interface. To support the data services, e.g., mobile Internet access and compressed video, with a bursty traffic nature, radio resource management (RRM) is an essential element that maximizes channel efficiency while guaranteeing the quality of services (QoS) by a proper configuration of data rate and access mode. Especially for the packet data services, a packet scheduling scheme plays an essential role to guarantee the QoS, which gives priority to packets with stringent delay or loss requirement while dealing with channel variation to give priority to users with (temporarily) good channel conditions. Since channel capacities of different users vary in time in an asynchronous manner, that is, even one user's channel is bad in the current time slot, it may become good after several time slots, scheduling may always find some users with good channel conditions.

Recently, a lot of new propositions and schemes for packet scheduling in 3G CDMA systems have emerged. However, few of them took the varying channel condition into account in the course of transmission rate scheduling under the cell load control, especially for the uplink of the DS/CDMA cellular systems.

This paper is organized as follows. In Section II, we review the design objectives of the cell load-based rate control scheme. In Section III, we propose a new scheme allowing for the different data rates subject to the different channel condition and furthermore, combined with the well-known proportional fairness scheduling algorithm, which warrants the fair sharing among all users. After presenting the simulation scenario in Section VI, numerical results are analyzed in Section V. Finally, conclusion is given in Section VI.

II. System Design Objective

To place a call on the reverse link of a DS-CDMA system, a Mobile Station (MS) must have sufficient power to overcome the interference and noise power generated by all other MSs within the band. Establishment of an additional call raises the interference levels seen by all MSs and thus, each MS must appropriately increment its transmission power accordingly to maintain call integrity. This process repeats itself with each additional MS until it reaches a limit at which a new MS, regardless of position, does not have enough power to overcome the level of interference generated by current MSs.

The uplink load η_{UL} of a DS/CDMA cellular network is defined as the ratio between the total received interference power at the BS (denoted by I_{tot}) and the total interference plus noise power (denoted by $I_{tot}+N$), i.e., $\eta_{UL} = I_{tot}/(I_{tot}+N)$ [3]. We can see from Figure 1 that the required signal-to-cell-site-noise-power ratio (SNR) per user rises in a non-linear fashion with uplink load η_{UL} [4]. Accordingly, the average power cost per additional mobile is much greater for a heavily loaded cell than a lightly loaded cell.

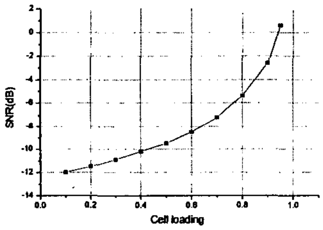

Figure 1. Required SNR per user as a function of cell load

Moreover, a cell that is too heavily loaded will not be able to accommodate statistical fluctuations in the channel and to aggregate transmission activity of its members. Due to the power constraint of MS, a high requirement of the received power level reduces both the cell coverage extent and the battery duration as well [4]. In general, the uplink load ranges from 0.6 to 0.7. Once the maximum possible uplink load is given, some control must be implemented to maintain that maximum value to achieve the maximum throughput. Assuming that fluctuation of the noise power is not significant as compared to the interference, that maximum cell load can be maintained by keeping the total received power constant. Recently, it has been noticed that a cell load can be controlled by a transmission rate control and scheduling scheme.

In [1], for example, it has been proposed that both transmission rate and power can be dynamically controlled in a distributed manner so as to maximize the aggregate throughput while maintaining the uplink load. More specifically, it deals with two different types of traffic, namely real-time and delay-tolerant traffic (denoted by class-1 and class-2 traffic, respectively). They proposed a scheduler at the BS that provides a SIR-based closed loop power control (CLPC) for all traffic classes while dynamically changing the data rate for delay-tolerant data traffics. The total interference I_{tot} at the BS is given as $I_{tot} = I_{intra} + I_{extra}$, where I_{intra} and I_{extra} denote the power received from mobiles in the target cell and the power received from other cells, respectively. In order to keep a constant uplink load value η_{UL}, the BS may defer some class-2 traffic by reducing the data rate so that the condition $I_{intra} = I_{tot} - I_{extra}$ may be fulfilled for the given value of I_{extra}. If a data rate of the real-time traffic is fixed by R_1 with the corresponding received power level P_1, then the required energy per bit-to-interference and noise spectral density ratio is given by

$$\gamma_1 = \frac{W}{R_1} \frac{P_1}{I_{tot} - P_1 + N} \tag{1}$$

where W is the chip-rate. In fact, the class-1 traffic will be served with higher priority than the class-2 traffic. For the specified minimum required energy per bit-to-interference and noise spectral density ratio of γ_1^*, the required power received at the BS from the class-1 traffic is given from (1):

$$P_1 = \frac{1}{1 + \frac{W}{\gamma_1^* R_1}} \frac{N}{(1 - \eta_{UL})} \tag{2}$$

In (2), we assume the perfect SIR-based CLPC so that the power received at the BS from all class-1 users is equal [1]. Now, the total power $P_{2,tot}$ that can be received from class-2 users will be the remaining power:

$$P_{2,tot} = I_{tot} - N_1 P_1 - I_{extra} \tag{3}$$

where N_1 denotes the number of active class-1 users. The remaining power of (3) is shared among all the N_2 class-2 users that are scheduled for transmission in the current scheduling period. The number of concurrent users and their data rate at this time will be determined by $P_{2,tot}$ and the minimum required energy per bit-to-interference and noise spectral density ratio of γ_2^*. In [1], it has been assumed that all the class-2 users are assigned the same data rate R_2. In particular, $R_2 = W / G_2$ where G_2 is the processing gain of class-2 user. Since all N_2 class-2 users are given the same data rate, their received power must be $P_2 = P_{2,tot} / N_2$. Assuming a perfect SIR-based CLPC, the spreading gain of the class-2 user is now given by

$$G_2 = \frac{\gamma_2^* (I_{tot} - P_2 + N)}{P_2} \tag{4}$$

Note that G_2 must be chosen from a set of the available processing gain values as specified in the real system. Since the maximum possible transmission power may be physically limited by $P_{\max}$ for each terminal (i.e., $P_2 \le P_{\max}$), an iterative process of determining the smallest possible number of the concurrent class-2 users subject to that power constraint has been proposed in [1]. The reason why it is seeking the smallest number of the concurrent users is based on the fact that throughput is maximized by the "one-at-time" scheduling strategy address in [7]. When each terminal is subject to the power constraint $P_{\max}$, we note that throughout can be further increased by allowing the multiple users at the same time. Once the number of concurrent class-2 users, N_2, is determined, [1] invokes a round-robin sharing (RRS) scheduling scheme, which cyclically serves N_2 users during each scheduling period among all active class-2 users. As each terminal is subject to independent channel fading variation, the actual required transmission power may exceed the maximum possible power constraint so as to meet the required level of power received at BS. To counteract this problem, a Power Margin (PM) F has been introduced in [1] and thus, the actual value of maximum possible transmission power is now set by $P_M = P_{\max} - F$.

We now address one important fact that has not taken into consideration in [1]. In reality, all the uplink users are faced with the different channel conditions, which implies that one with the favorable channel condition can increase its data rate and vice versa. In other words, the different channel conditions can be taken into consideration, which leads to the different data rates for the different uplink users. In the subsequent section, we propose a new transmission rate control algorithm with the different scheduling algorithm, which takes the different channel conditions into account for determining the individual data rate so as to maximize the throughput of the class-2 users.

III. Proposed Scheduling Algorithm

All the traffic models considered hereafter is exactly the same as in [1], e.g., two traffic classes of the real-time and delay-tolerant traffic. Therefore, (1) and (2) are still valid for the class-1 users. Furthermore, (3) is also valid for our current discussion.

Let α_i be the channel gain (including all the effects of path loss, shadow fading, and etc.) for user i of the class-2, which is independent of each other. Then, the maximum received power of the corresponding user at the BS will be

$$P_{2,i} = \alpha_i \cdot P_M, \quad i = 1, 2, \ldots, N_{2,tot} \tag{5}$$

where $N_{2,tot}$ is the total number of active class-2 users and $P_M = P_{\max} - F$. Since each user is faced with the different channel gain, i.e., the different level of the received power at the BS, (4) must be rewritten for each user i:

$$G_{2,i} = \frac{\gamma_2^* (I_{tot} - P_{2,i} + N)}{P_{2,i}} \tag{6}$$

Here, we again assume the perfect SIR-based CLPC. Then, the data rate of user i is given by

$$R_{2,i} = W / G_{2,i} \tag{7}$$

Under the varying data rate, the RRS scheduling scheme in [1] is not appropriate any more, since a fair share of capacity is not warranted for each user. This is the same problem addressed for the cdma-2000 1X-DO (HDR: High Data Rate) [2], which deals with the packet scheduling issue for the downlink of CDMA system. In particular, only a single user with the best channel condition is allowed to transmit at its maximum allowable data rate in the system. To warrant the fairness among all the users, a general scheduling scheme adopted for the cdma-200 1X-DO is the "proportional fairness" algorithm. A basic idea of the algorithm is that the scheduler sends data to the mobile that has the highest *DRC/R* where *DRC* is the rate requested by the mobile in a given slot and *R* is the average rate received by the mobile over a window of appropriate size [2]. In this manner, each user is served in slots in which its requested rate is closer to the peak compared to its recent requests.

In fact, we are dealing with a similar problem, yet for the uplink, in which however, the same scheduling algorithm can be still applied. As in [2], we let $\overline{R}_{2,i}(t)$ be the estimation of the average rate for the user i of class-2 traffic, measured by the scheduling period t. At each scheduling instance, the BS will serve the user i with the highest $R_{2,i}(t)/\overline{R}_{2,i}(t)$ with rate $R_{2,i}$. After that, if there is still some power left, the scheduler will find the user with second highest $R_{2,i}(t)/\overline{R}_{2,i}(t)$ and then serve it. The scheduler keeps doing so until reaching a point where there is not enough power left to serve the next whole user, in that case, the BS serves a part of the corresponding packet and go on to the next scheduling period.

For each user i of class-2 traffic, its average rate will be updated every frame, according to

$$\overline{R}_{2,i}(t+1)=\left(1-\frac{1}{t_c}\right)\cdot\overline{R}_{2,i}(t)+\frac{1}{t_c}\cdot R_{2,i}(t) \tag{8}$$

where t_c is a size of moving-average window in terms of the scheduling periods. A user that is not currently receiving service has 0 for his current rate of transmission. Even users for whom the scheduler has no data to send also get their average rate updated.

In fact, we combine the cell loading-based transmission rate control with the proportional fairness (PF) algorithm to form a new rate scheduling scheme for the uplink of CDMA cellular system. In Figure 2, the overall algorithm is described with a flow chart. In the flow chart, the delay T denote the scheduling period and in general, it is set as the frame length. Note that $N_{1,tot}$ and $N_{2,tot}$ denote the total numbers of class-1 and class-2 users while N_1 and N_2 denote the number of users being served in the current scheduling period, respectively.

IV. Simulation Scenario

We use the same simulation environment as in [1]. We consider a cellular system with a reference cell and three tiers of adjacent cells, all together 37 cells. The cellular architecture is given by the hexagonal regular layout. The carrier frequency is 2 GHz and the path-loss model is $L=128.1+37.6\log_{10}R$ in dB. The shadowing fading and Rayleigh fading are also considered and the details can be referred to [1]. We are only interested in the mobiles in the center cell. Each mobile in the cell moves following linear trajectories and changes direction every T seconds with probability p and with an angle q (with respect to previous direction), which is uniformly distributed in the interval $[-\pi/4,\pi/4]$. When an MS reaches outside the center cell borders, it will be regenerated at a new random position in the cell. Without loss of generality, the other cell interference was fixed at a constant for the sake of simplicity. Just for the comparison purpose, such a simplification seems to be acceptable.

For every slot time τ during a scheduling period, each BS performs a power control, i.e., it measures the actual SIR of its own MS, compares them to the target value γ^*, and updates the power levels for the MS accordingly. Since the required receiving power is set to be constant during the scheduling period, the mobiles may not be able to counteract the channel fluctuation even with their maximum transmission power P_{max}. In this case, an outage event occurs (i.e., the target level of γ^* cannot be achieved).

We use the ON-OFF model for class-1 traffic. The sojourn times of both ON and OFF states are exponentially distributed with averages of 1 second and 1.35 seconds, respectively. Meanwhile, we assume that class-2 traffic is always active. Table 1 summarizes all the parameters used our simulation.

Table1. Parameters used in simulation

Parameters		Value
MS speed		50km/h
Scheduling period (frame duration)	T	10ms
Slot time	τ	0.667ms
Variance of log-normal shadow fading	σ	10dB
Bandwidth	W	3.84 MHz
The probability of direction changing	p	0.2
The data rate of class-1 user	R_1	15 kbit/s
Spreading gains for class-2 users	G_2	2^x, $x\in\{2,3,\Lambda,8\}$
The required E_b/N_0 for class-1 users	γ_1^*	1.5dB
The required E_b/N_0 for class-2 users	γ_2^*	2.5dB
The number of class-1 users in the cell	N_1	25
The number of class-2 users in the cell	N_2	20
The max. possible power of a terminal	P_{max}	0.25 W

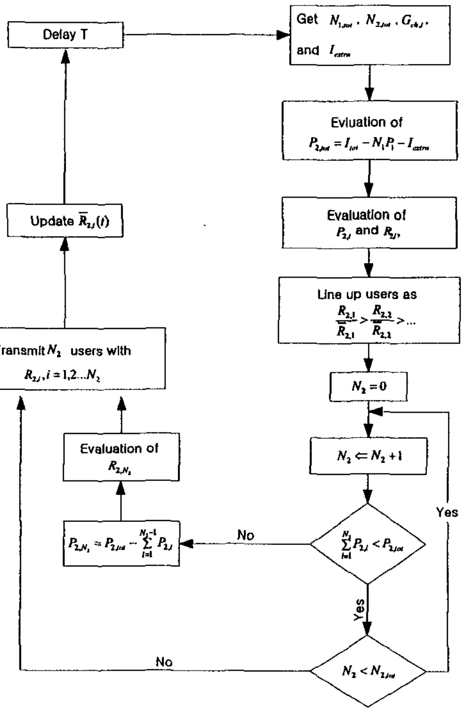

Figure 2. Flow Chart of the proposed algorithm

V. Numerical Results and Analysis

In order to prove that our proportional fairness (PF)-based new algorithm outperforms the RRS scheme in [1], their throughput and outage performances are compared.

Figures 3 and 4 show the average throughput (rate) and outage performance of class-2 users. From these figures, we find that the throughput of our new algorithm is similar to that of RRS scheme in [1] when uplink load is low. When uplink load becomes higher, however, the average data rate of class-2 users with PF became higher than that with RRS. That is because we chose the users with better channels to transmit in PF, while the transmission rate is governed by the user with the worst channel in the RRS scheme. Consequently, the RRS scheme will admit more users to transmit simultaneously at high cell load (refer to Figure 5). In fact, the self-interference among the concurrent users lowers the their transmit rates.

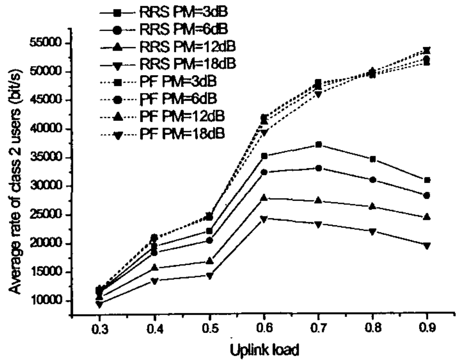

Figure 3. Average throughput per class-2 user

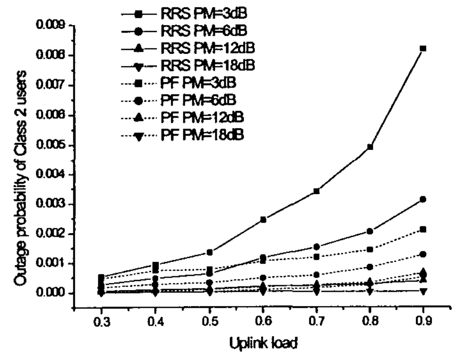

Figure 4. Outage performance of class-2 users

As expected, the outage rate of PF-based approach is also much lower than that of RRS. That is because the user terminals with better channel conditions can transmit with lower power and consequently, they will have more power left to counteract the channel fluctuation during the scheduling period. On the contrary, the RRS does not consider the channel conditions when deciding which user to serve, so the users being served often have to transmit with high power, which increases the probability of being running out of power. While RRS algorithm is very fair to users by serving the users with same data rate in a round-robin fashion, PF algorithm warrants fairness by giving some priority to those received less services.

In Figure 5, the average number of admitted class-2 users per cell for a scheduling period was presented as a function of the uplink load for the different values of power margins. We see that the allowed number of class-2 users in the PF-based scheme is much less than in RRS, and almost not influenced by the change of uplink load in this simulation. That is due to the fact that the users being served in the PF-based scheme are always the ones with good channel conditions. Those users can use much more interference resources in the BS than those with worse channels.

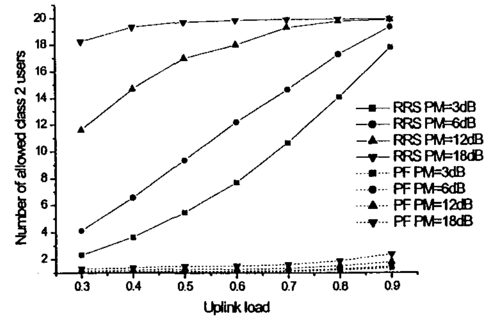

Figure 5. The number of admitted class-2 users per cell

We can also see that the throughput and the outage probabilities all increase with the uplink load. Furthermore, the outage probability can be reduced by the power margin, but reducing the transmission rate at the same time. So, it is possible for us to use cell loading control and power margins to tradeoff the throughput and the outage probability in the course of scheduling.

VI. Conclusion

As the previous work on the cell load-based transmission rate control does not take the varying channel condition into account, we found that it could be further improved with taking advantages of the maximum possible data rate achievable under the given channel condition. The unfairness that may be incurred by the different data rates among the users has been fixed by employing the proportional fairness algorithm. Our simulation results obviously indicate that the proposed scheme outperforms the original cell load-based rate control with the RRS scheduling scheme in [1].

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