Channel-Adaptive GPS Scheduling for Heterogeneous Multimedia in CDMA Networks

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Abstract. Wireless packet-scheduling is a crucial component for providing quality of service (QoS) in CDMA networks. In this paper, we propose channel-adaptive rate-scheduling based on Generalized Processor Sharing (CA-GPS) to guarantee minimum service rate and to provide proportional fairness among heterogeneous multimedia traffic for QoS differentiation. The CA-GPS scheduler assigns different GPS weights according to traffic priorities, to provide differentiated services under time-varying channel conditions. Soft-uplink capacity analysis is performed and used to improve the utilization of CDMA system resources. The performance analysis and evaluation of proposed CA-GPS is achieved via simulation in terms of achievable throughput, delay, and proportional fairness.

1 Introduction

There are many needs to support heterogeneous multimedia traffic having different quality of service (QoS) requirements in wideband CDMA networks. This paper tackles an efficient scheduling to provide maximum uplink system throughput, minimum average delay and proportional fairness in accordance with traffic priority through dynamic resource allocation under the different traffic QoS requirements and time-varying channel conditions.

An ideal fairness scheduler is Generalized Processor Sharing (GPS) [1] which assigns each traffic a different fixed weight and dynamically allocates bandwidth to all backlogged traffic according to their weights and traffic load. Several GPS-based schedulers have been proposed for wired/wireless networks [2~7]. However these schedulers are implemented using a time-scheduling approach, which represents high complexity due to the extensive computation for each packet's virtual time. The time-scheduling approach is suitable for time-division multiple access (TDMA) or hybrid time division duplex (TDD)/CDMA. The CDMA system is interference-limited and the system capacity depends on the sum of the allocated rate in each block of data. The optimum scheduling scheme is required to incorporate relationships with these traffic rates and received powers.

Previous work relating to GPS-based uplink- scheduling for CDMA environments are mentioned in Refs. [4][8][10]. However the available system capacity in this work is treated as static, with patterns that do not vary over time, resulting in poor total

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system throughput and which cannot adapt efficiently to channel conditions. Also the scheduling schemes do not consider QoS requirements and requested QoS differentiation at the same time. Efficient scheduling in a CDMA system should consider entire CDMA system resources representing as **soft capacity** [8]. Uplink system capacity is especially subject to the variation of signal-to-interference ratio (SIR) and requested rates of users in the cell.

In this work, we will tackle channel-adaptive wireless packet scheduling method, considering the time-varying system capacity in order to maximize the system throughput while providing proportional fairness using different GPS weightings, and also providing QoS differentiation in accordance with traffic priorities. This paper proposes QoS-aware traffic and channel-adaptive scheduling based on GPS to estimate up-link capacity and to provide weighted service rates upon traffic priority. Our scheduling function has the features of (1) higher system throughput by analyzing uplink capacity; (2) QoS differentiation among traffic; and (3) proportional fairness via different GPS weights; and (4) guaranteeing the minimum service rate in time-varying CDMA systems.

This paper is organized as follows: The system model we consider in CDMA cellular networks is briefly described in Section 2. The formulation of a CDMA system capacity analysis is described in Section 3. In Section 4, we propose a channel-adaptive GPS (CA-GPS) scheduling algorithm to achieve objectives of high system throughput, delay, and fairness under time-varying system capacity. Simulation results are shown in Section 5 to demonstrate the performance of CA-GPS schemes, followed by our conclusion in Section 6.

2 System Model

Direct Sequence (DS)-CDMA systems are considered in this work. This paper focuses on an uplink scheduler that resides at each base station (BS). The physical data channels in the uplink are distinguished by pseudo-noise (PN) codes. In this paper we assume the uplink capacity is interference-limited and is not limited by the number of available PN codes due to multiple-access interferences (MAI).

The power control of the user with a low speed is nearly perfect for maintaining the target bit error rate (BER). On the other hand, the power control is difficult for fast-moving users due to fast channel fading. In this paper we assume that all users in the cell move slowly for perfect power control without loss of generality.

The transmitting channel rate of each mobile station (MS) is scheduled on a time-slot basis. The required BER is different according to voice, video, and data traffic. The minimum SIR to meet the minimum required BER, however, is targeted to satisfy CDMA systems. The leaky-bucket regulator is required to shape each traffic source in order to achieve a bounded delay for a user. Fig. 1 is the system queueing model for our proposed CA-GPS scheduling. All active users share time-varying uplink capacity and the scheduler can allocate each user's rate differently. The available system capacity may be different from different time slot.

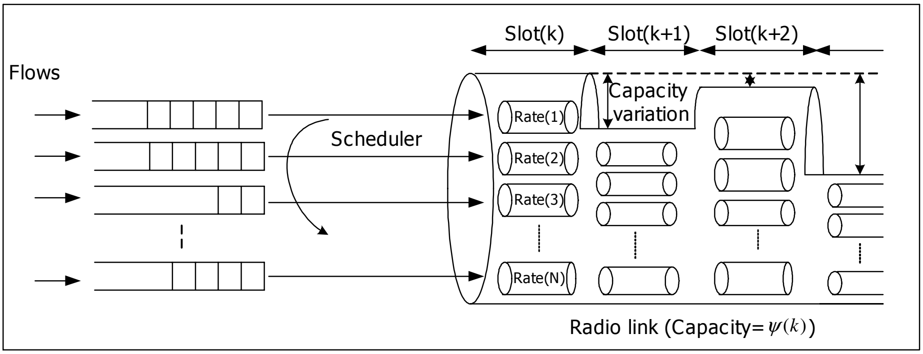

Fig. 1. System model of CA-GPS

3 The Estimation of CDMA System Capacity

Uplink capacity of a CDMA system is dynamically changing according to time and users' position. In this section, we will estimate the uplink capacity in order to maximize the total throughput. Let us consider the uplink of a CDMA system containing B(t) backlogged mobile users at time t. Without loss of generality we assume that each user has only one flow active at a given time. The transmission power of a mobile user i is denoted by p_i. Let G_i be the spreading gain of user i and γ_i be its minimal SIR required to satisfy its QoS requirements. The corresponding QoS constraints are given by: [10]

$$\frac{G_i h_i(t) P_i}{\sum_{j=1, j\neq i}^{B(t)} h_j(t) P_j + W\eta_0} \geq \gamma_i \quad i = 1,2,\ldots,B(t) \tag{1}$$

where W : Bandwidth, $h_i(t)$: Channel gain at time t, η_0 : One-sided power spectral density of additive white Gaussian noise.

The optimal power solution can easily be derived when all QoS constraints are met with equality.

$$\frac{G_i h_i(t) P_i^*}{\sum_{j=1, j\neq i}^{B(t)} h_j(t) P_i^* + W\eta_0} = \gamma_i \quad i = 1,2,\ldots,B(t) \tag{2}$$

Eq. (2) can be modified to:

$$h_i(t) P_i^* = \frac{\gamma_i}{G_i + \gamma_i} \left[\sum_{j=1}^{B(t)} h_j(t) P_j^* + W\eta_0 \right] \tag{3}$$

If we write Eq. (3) for all *i*'s and add those equations, it can be shown that:

$$\sum_{i=1}^{B(t)} h_i(t)P_i^* = \frac{\sum_{i=1}^{B(t)} \frac{\gamma_i}{G_i+\gamma_i}}{\left(1-\sum_{i=1}^{B(t)} \frac{\gamma_i}{G_i+\gamma_i}\right)} W\eta_0 \tag{4}$$

By employing Eq. (4) in Eq. (3), the optimum power solution is determined:

$$P_i^* = \frac{W\eta_0}{h_i(t)\left(1-\sum_{j=1}^{B(t)} \frac{\gamma_j}{G_j+\gamma_j}\right)} \frac{\gamma_i}{G_i+\gamma_i} \tag{5}$$

Since the power value should be positive and limited, the following necessary condition, $\sum_{i=1}^{B(t)} \frac{\gamma_i}{G_i+\gamma_i} < 1$, must be satisfied.

However, when the left-hand side of the necessary condition is close to 1, the optimal power levels may be too high to be sustainable. Moreover, the increase in the total power of users in one cell may adversely affect the surrounding cells and stimulate an increase in intercell interference. Therefore, it is necessary to impose the inequality:

$$\sum_{i=1}^{B(t)} \frac{\gamma_i}{G_i+\gamma_i} < 1-\delta, \quad \delta: \text{Small positive number} \tag{6}$$

From now on, we're going to show the available uplink capacity based on above statements. The received power level at the base station is restricted. Here, the power constraints are defined as:

$$0 \le P_i \le P_i^{\max} \tag{7}$$

where $P_i^{\max}$ is the maximum transmission power limit of user *i*. Using Eqs. (5) and (7) implies that [10][11]:

$$\sum_{i=1}^{B(t)} g_i < 1 - \frac{W\eta_0}{\min_i\left(P_i^{\max} h_i(t)/g_i\right)} \tag{8}$$

where $g_i \left(\triangleq \frac{\gamma_i}{G_i+\gamma_i}\right)$ is power index of user *i*.

Finally, we can obtain the available maximum uplink capacity at time *t*, $\psi(t)$, by comparing Eqs. (6) and (8).

$$\psi(t) = 1 - \frac{W\eta_0}{\min_i\left(P_i^{\max} h_i(t)/g_i\right)} \tag{9}$$

Eq. (9) indicates that $\psi(t)$ is mainly affected by channel gain and power index of user *i*.

4 Proposed Channel-Adaptive GPS (CA-GPS) Scheduling

In this section, the CA-GPS scheme is introduced, allocating resources to all users, while considering the soft capacity. Let $r_i(k)$ be the allocated service rate of user *i*, $B(k)$ and $R(k)$ be the set of active users and the total amount of allocated service rates (i.e., $\sum_{i\in B(k)} r_i(k)$) for time slot *k*, respectively. Also, let $\psi(k)$ be the available maximum uplink capacity in time slot k. ϕ_i denotes the weight of user *i*. The set of user *i* is not allocated by any service rate that is represented for compensation as $\alpha(k)$. The CA-GPS scheduler allocates each allocated rate to user *i*, $r_i(k)$, using the following steps as in Fig.2:

In this algorithm, we calculate $R(k)$ using $\psi(k)$ for estimating the available uplink capacity. Users have fixed-service rates in previous work. However we consider a minimum service rate in order to serve more users in the same period. This causes the main difference in terms of total system throughput and efficiency. After that we allocate the extra resources to other active users considering various traffic priorities. This is for providing proportional fairness to all active users.

The case of branch 1 is for bad channel. If the amount of all active users' minimum service rates is more than $R(k)$, we allocate resources to users randomly until $C(k)$ is less than $\min_i(r_i^{\min})$ as shown in the middle area in Fig.2. Since traffic has higher priority and a higher minimum service rate, we have to check the minimum service rates of all users in order to maximize utilization in the remaining resources. The reminder of resource has to be compared with priority order and allocated to the other user having a minimum service rate less than the reminder. If a minimum service rate is not considered as other works, we can't guarantee quality of service when channel state is bad. We give more priority to the total system throughput rather than achieving proportional fairness. The case of branch 2 is for good channel. (we show it in the left side of Fig.2).

Another feature in this algorithm is compensation, i.e., we serve users who were not served on time due to the channel state condition. This also improves total system throughput. Consequently, the proposed algorithm provides proportional fairness and higher throughput compared to other GPS-based schemes.

The above resource allocation procedure is aimed at finding $r_i(k)$ of user *i,* while maximizing the total throughput and satisfying the GPS fairness constraint. This algorithm also provides the minimum service rate with higher priority and increases the throughput of each user due to the compensation in subsequent user allocation for the users who are in the set $\alpha(k)$ and received insufficient services in previous time interval.

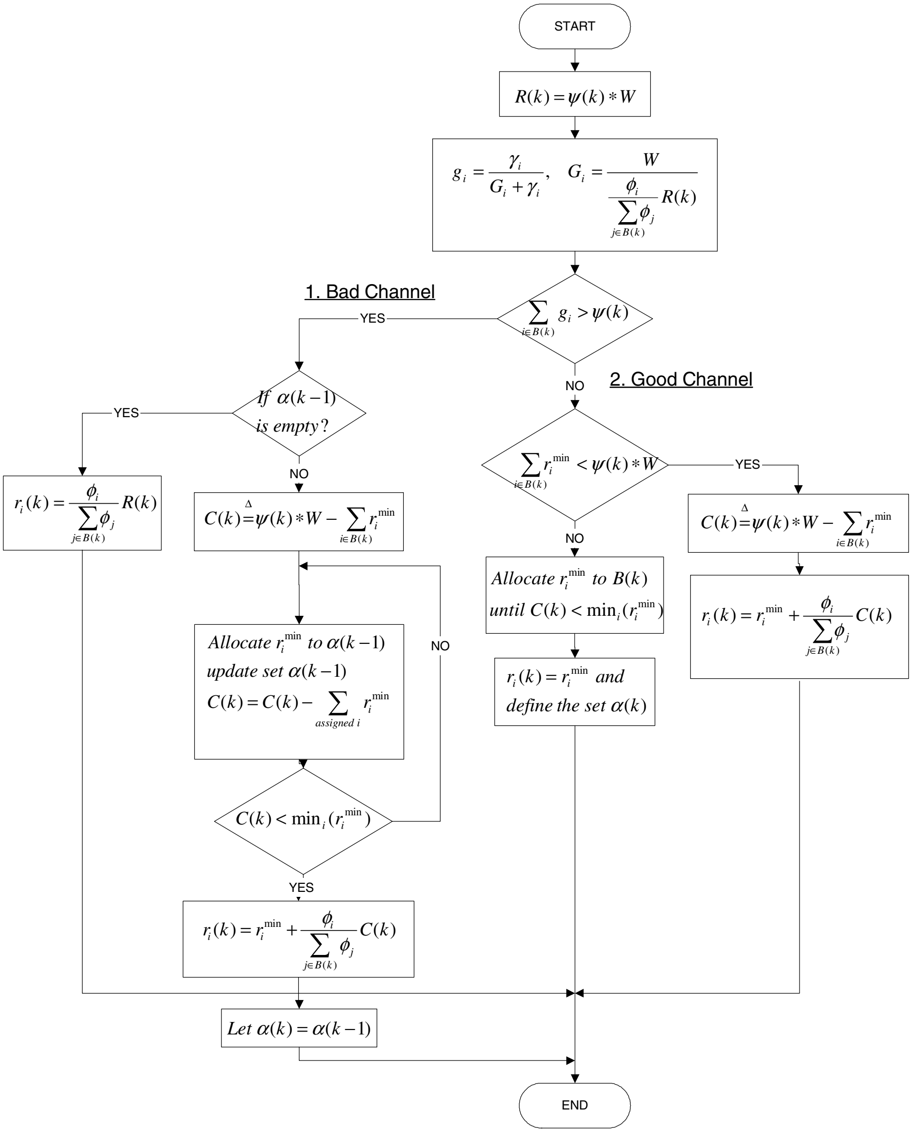

Fig. 2. CA-GPS Algorithm

5 Simulation Results

In this section, simulation results are presented to demonstrate the performance of the proposed CA-GPS scheme in terms of delay, system throughput and proportional fairness. The scheduling period T is 10ms. In simulation, the CA-GPS scheme is compared with the CDGPS [8] under heterogeneous traffic environments.

The total bandwidth is assumed to be a constant W = 5Mb/s. The total available uplink capacity is estimated by solving Eq. (9). Ten flows are considered, and assigned as different weights. All flows are modeled by a Poisson process with average arrival rate λ and packet length L, shaped by a leaky-bucket regulator for providing the bounded delay. The corresponding values of all the parameters used throughout our study are shown in Table 1 [10][12].

Table 1. Simulation Parameter Values

Parameter	Value
Packet size	5kbits
AWGN spectral density (η_0)	10^{-6}
Minimum channel gain $(h_i(t))$	0.25
Maximum transmission power $(P_i^{\max})$	0.5W
Weight(user 0,1,2,3,4,5,6,7,8,9)	(1,1,1,1,1,2,2,2,4,4)
Required SIR (E_b/I_e)	5dB
Scheduling cycle (T)	10ms
Minimum required service rate $(r_i^{\min})$	192,320,640kbps

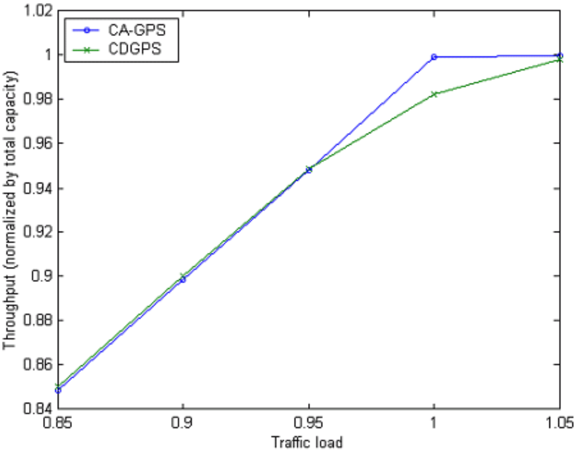

Fig. 3. Throughput comparison: CA-GPS and CDGPS

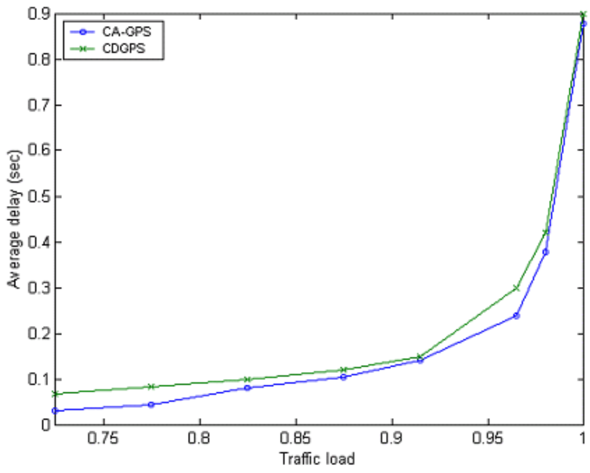

Fig. 4. Average delay

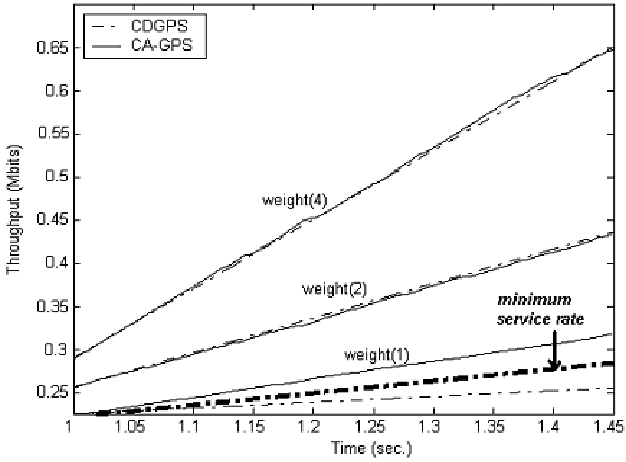

Fig. 5. Proportion fairness

Fig. 3 shows the throughput comparison of being used CA-GPS and CDGPS. The traffic load is the sum of average arrival rates of the ten data flows. The proposed scheme throughput is higher than CDGPS because CA-GPS uses the concept of minimum service rate. It is shown that CA-GPS can improve the uplink throughput.

Fig. 4 shows the average delay with different system loads. In this figure, it can be seen that the average delay performance of CA-GPS with a soft capacity is better than CDGPS with a fixed capacity. The minimum required service rate is the first consideration in CA-GPS. Therefore, more users can be served.

Fig. 5 shows the throughput with different weights. Flow weights have proportions of 1:2:4 and the throughput of flows are close to the proportion in CA-GPS. On the other hand, CDGPS does not consider the minimum service rate. Consequently, the flow has a lower weight that sometimes cannot be served when the channel condition is bad.

6 Conclusion

In this work, an efficient scheduler is proposed to satisfy the QoS requirements of multimedia traffic in a CDMA uplink system. The time-varying capacity is estimated with the consideration of a user's QoS requirements, channel fading effect, and transmitting power. The proposed channel-adaptive scheduling based on GPS (CA-GPS), adapts the time-varying channel capacity and minimum required service rate in order to improve system utilization, average delay and proportional fairness. The performance of proposed scheduling is compared with CDGPS [8] as "fixed capacity" shown in Fig. 3~5. The proposed scheduling method is closer to fluid-modeled GPS than other GPS-based scheduling for CDMA systems.

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