Power Control of CDMA Systems with Successive Interference Cancellation Using the Knowledge of Battery Power Capacity*

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Abstract— Successive interference cancellation (SIC) has been used in multi-rate code division multiple access (CDMA) systems to eliminate the co-channel interference. In SIC, the required transmission power of a certain user can be reduced if it is detected late in the cancellation order as the interferences caused by the users that are detected before have been cancelled. In this work, we study the power control strategy based on different orderings for the SIC given the knowledge of the battery capacity of the mobiles. In particular we propose different ordering schemes for SIC for different optimization objectives such as minimizing the total power, maximizing the minimum transmission/connection time for a group of users within the same cell and maximizing the total amount of data transmitted for a group of users. Experimental results show that significant improvement can be achieved by using the proposed ordering methods.

1. INTRODUCTION

Power control is an important vehicle for performing several network operations such as admission control, link QoS maintenance, channel probing, resource allocation, and hand-offs for wireless systems [1]. In addition, power control is essential for optimizing the energy consumption of wireless system especially in minimizing the transmitter power and maximizing the battery life of the mobile nodes [2].

Multi-rate code division multiple access (CDMA) systems [3] are becoming popular for the next generation wireless communication systems. One of the limiting factors for the performance and capacity of these systems is the interference seen by a user, which is caused by the other users in the systems. To reduce this interference, successive interference cancellation has been proposed [4]. In perfect SIC, for a particular user, only those users that are detected after him would generate interference for its detection. So the later the user is detected, the less transmission power is required as less interference is seen. Various power control strategies based on different interference cancellation ordering schemes can be used to satisfied different optimization objectives. In [5] an ordering scheme has been proposed to minimize the total transmission power of a group of users within the same cell.

However, few attentions have been given to the issues of power control considering the mobile nodes' battery capacity. In this paper, using the uplink of a single cell multi-rate code division multiple access (CDMA) systems with perfect successive interference cancellation (SIC) as our reference system, we present a framework of power control for different optimization objectives based on different ordering schemes for SIC with the knowledge of the battery capacity of the mobiles. One obvious objective is to minimize the total power consumption of all the users. In other applications, we may want to have all the users connected at the same time as long as possible. Here if the base-station finds that one of the users is about to run out of battery, it can change the detecting order of the SIC so that this user's signal is the last one to be detected so to reduce the required transmission power to extend the transmission time. In this way, the minimum transmission time of the whole group is extended.

For other applications, we may want to maximize the total number of transmission data of a group of users before all of them run out of battery. Assuming that all of them have the same channel loss and Quality of Service requirement, ranking the users in the ascending order of their battery capacity allows those users with less battery capacity run out of battery first so that they will generate less interference to others. The total number of transmission data can be increased in this way. Instead of maximizing the total number of transmission data, we can also maximize the sum of the transmission time of each user weighted by a rate. This is equivalent to maximizing the total revenue if the system charges the users based on the transmission rate and the transmission time.

The rest of the paper is organized as follows. We first introduce SIC, the system specification and the notation in session 2. Then we will present different optimization strategies for SIC in section 3. Experimental results for each optimization strategy will be presented. Finally, session 4 gives the conclusions.

2. SIC AND NOTATION

2.1. Successive Interference Cancellation

The performance and the capacity of the CDMA system can be significantly degraded due to the co-channel interference and near-far effect [3]. To overcome these problems, interference cancellation (IC) techniques have been proposed to increase the capacity by canceling the multiple access interference [4]. The idea of IC is to cancel the inter-user interference based on the previously detected symbols from other users to make more reliable symbol demodulations. IC can be classified into two types. They are

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successive interference cancellation (SIC) and parallel interference cancellation (PIC), respectively.

The structure of the SIC is shown in Fig. 1. The received signal power of each user is measured after the matched filter and the users are ranked in certain order. There are K Demodulation & Signal Recovery Units (DSRUs) where K is the number of simultaneously communicating users. Each DSRU performs matched decision (dispreading), channel estimation, tentative symbol decision, and replica generation of each user. The interference replicas of the first *i-1* users are subtracted from the received spread signal y(t) before sending to the i^{th} DSRU.

2.2. System specification and notation

In this work, we consider the uplink of a single cell multi-rate CDMA system with perfect SIC, i.e., perfect channel state information (CSI) is assumed and the users' signals can be decoded and regenerated correctly so that the interference to other users is totally eliminated when the signal is cancelled. Different services with different data rates and QoS requirements are supported. The QoS requirement is usually specified in the form of bit error rate (BER) or frame error rate (FER). We assume the QoS requirement is specified by an equivalent received E_b/N_o requirement. Different rates are achieved by using different processing gains with a fixed chip rate. Also the total bandwidth is used by all users.

To formulate the optimization problem, we define the notations for the following useful parameters:

N: the number of users in the cell.
W: the bandwidth of the system
E: the battery capacity vector of the users $[E_1, E_2, \dots, E_N]$
V: the normalized charge vector of the users $[V_1, V_2, \dots, V_N]$
R: the rate requirement vector of the users $[R_1, R_2, \dots, R_N]$.
Q: the QoS requirement vector of the users $[Q_1, Q_2, \dots, Q_N]$.
P: the transmit power vector of the users $[P_1, P_2, \dots, P_N]$.
h: the channel power gain vector of the users $[h_1, h_2, \dots, h_N]$.
E_b: bit energy.
N_o: Additive White Gaussian Noise (AWGN) with one-side power spectral density.
The expression of the E_b/N_o of the i^{th} user is given by [4]

$$\left(\frac{E_b}{N_o}\right)_i = \frac{W}{R_i}\frac{h_i P_i}{\sum_{j=i+1}^{N} h_j P_j + N_o W} \qquad i = 1, \dots N \tag{1}$$

3. DIFFERENT SIC ORDERING STRATEGIES FOR DIFFERENT OPTIMIZATION OBJECTIVES

3.1. Minimizing the total transmission power

Given the rates and the QoS requirements of the users, the objective of the power control is to minimize

$$\sum_{i=1}^{N} P_i \tag{2}$$

subject to the constraints

$$\left(\frac{E_b}{N_o}\right)_i \ge Q_i \quad i = 1, \dots, N \tag{3}$$

From [5], it has been known that ranking the users in the descending order of the channel gain (h) can minimize the total transmission power of the users, regardless of the users' data rate and QoS requirements. We call this ordering scheme the Gain ordering scheme.

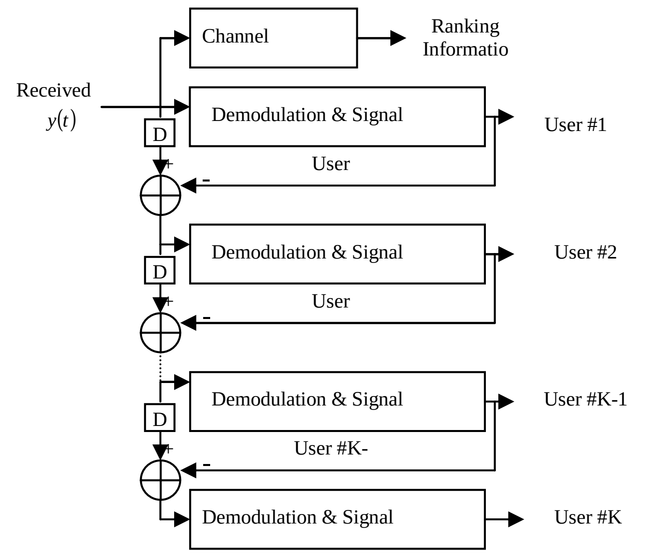

Fig.1 The structure of SIC

3.2. Maximizing the minimum transmission time

Given the rate and the QoS requirement, and the battery capacity of each user, the objective of this power control scheme is to maximize

$$\min\left(\frac{E_1}{P_1} \cdots \frac{E_N}{P_N}\right) \tag{4}$$

subject to the constraints of (3). Here we propose two schemes. The first is a static ordering scheme which assumes the order cannot be changed once it is determined. The second one is a dynamic ordering scheme in which the ordering can be changed from time to time.

3.2.1. Static ordering scheme

From [5], it is shown that the required transmission power under a certain detecting order is given by

$$P_i = N_o W \frac{1}{h_i}\frac{R_i Q_i}{W}\prod_{j=i+1}^{N}\left(1 + \frac{R_j Q_j}{W}\right) \quad i = 1, \dots, N \tag{5}$$

For static ordering scheme, we assume that the detecting order is decided at the beginning of transmission and it cannot be changed before one of the users run out of battery.

Let A and B be the users i and i+1, respectively, (i.e., two consecutive users) rank according to the decoding order of the SIC scheme. Keeping the decoding order of all other users unchanged, there are two possible orderings for these two users. If user A's signal is cancelled before detecting user B's signal, the required transmitting power of A and B are

$$\begin{cases} P_A = N_o W \dfrac{1}{h_A}\dfrac{R_A Q_A}{W}\left(1 + \dfrac{R_B Q_B}{W}\right)\prod_{j=i+2}^{N}\left(1 + \dfrac{R_j Q_j}{W}\right) \\ P_B = N_o W \dfrac{1}{h_B}\dfrac{R_B Q_B}{W}\prod_{j=i+2}^{N}\left(1 + \dfrac{R_j Q_j}{W}\right) \end{cases} \tag{6}$$

respectively. If user B's signal is cancelled before detecting user A's signal, the corresponding transmission power values become

$$\begin{cases} P_A^{'} = N_o W \dfrac{1}{h_A} \dfrac{R_A Q_A}{W} \prod_{j=i+2}^{N} \left(1 + \dfrac{R_j Q_j}{W}\right) \\ P_B^{'} = N_o W \dfrac{1}{h_B} \dfrac{R_B Q_B}{W} \left(1 + \dfrac{R_A Q_A}{W}\right) \prod_{j=i+2}^{N} \left(1 + \dfrac{R_j Q_j}{W}\right) \end{cases} \quad (7)$$

Then, it's easy to find that

$$h_A P_A + h_B P_B = h_A P_A^{'} + h_B P_B^{'} \quad (8)$$

It means that for the users whose signals are detected before these two consecutive users, they see the same total interference created by these two users, regardless of their ordering. For the users whose signals are detected after these two users, they do not experience any interference from these two users, as their signals have already been cancelled completely. Therefore, the ordering of two consecutive users in the SIC scheme does not affect other users' transmission power.

Let T_{AB} and T_{BA} represent the minimum transmission time under these two orderings, respectively, we have

$$T_{AB} = \min\left(\frac{E_1}{P_1}, \cdots \frac{E_A}{P_A}, \frac{E_B}{P_B}, \frac{E_N}{P_N}\right), T_{BA} = \min\left(\frac{E_1}{P_1}, \cdots \frac{E_B}{P_B'}, \frac{E_A}{P_A'}, \frac{E_N}{P_N}\right) (9)$$

From (6) and (7), we can find that

$P_A > P_A^{'}, P_B < P_B', \frac{E_A}{P_A} < \frac{E_A}{P_A^{'}} \, and \, \frac{E_B}{P_B} > \frac{E_B}{P_B^{'}}$.

If $\frac{E_A}{P_A} \le \frac{E_B}{P_B'}$, then $T_{AB} \le T_{BA}$ and user B should be detected first. Otherwise user A should be detected first.

From (6) and (7), we can derive that

$$\frac{E_A}{P_A} \le \frac{E_B}{P_B'} \Rightarrow \frac{h_A E_A (W + R_A Q_A)}{R_A Q_A} \le \frac{h_B E_B (W + R_B Q_B)}{R_B Q_B} \quad (10)$$

Let $G_i = \frac{E_i h_i}{R_i Q_i}(W + R_i Q_i)$, and we call it the ***time factor*** of the user. We can conclude that if there are two consecutive users whose time factors are not in descending order, we can switch their decoding orders in the SIC scheme to increase the minimum transmission time of them.

By simple induction, we can show that one of the optimal ordering to maximize the minimum transmission time if the ordering can not be changed during transmission is to rank their detecting orders according to their ***time factors*** in descending order. We call this static ordering scheme.

3.2.2. Dynamic ordering scheme

When the decoding order can be changed during the transmission time, the static ordering scheme may not be optimal. This can be shown by the following argument. Assume that all the users suffer the same channel loss, have the same battery capacity and the same transmission rate. In the beginning, we can see that the minimum transmission time under any ordering scheme is the same. However after some time, the remaining battery capacities of the users are no longer the same since the transmission power required for each user is different according to the detection order. If we can re-order them and let those users with less battery capacity be detected later to reduce their required transmission power, the minimum transmission time can be extended.

Actually, if we find that under the current order, the user that will run out of battery first has an instantaneous ***time factor*** less than that of one of the users' who is detected after him, we can extend the minimum transmission time of the group of users by simply swapping their detecting orders.

Based on this, we propose the following dynamic ordering scheme

Step1: Compute the ***time factor*** of each user within the group and arrange them in the descending order of time factor.

Step2: Compute the required transmitting power of each user under this ordering (P_i). Find the user that will run out of battery first. Let it be the user m among N users and there are m-1 users who are decoded after it. User m would run out of battery after time $\Delta t_1 (= \frac{E_i}{P_i})$ under the current decoding order.

Step3: Compute the time (Δt) when at least one of the other m-1 user's instantaneous time factors is not less than user m's instantaneous time factor, i.e.

$\Delta t = \min(t_0 \dots t_{m-1})$ (11)

where

$$\frac{(E_m - P_m t_i) h_m}{R_m Q_m}(W + R_m Q_m) = \frac{(E_i - P_i t_i) h_i}{R_i Q_i}(W + R_i Q_i)$$

$$t_i = \frac{E_m R_i Q_i h_m (W + R_m Q_m) - E_i h_i R_m Q_m (W + R_i Q_i)}{P_m R_i Q_i h_m (W + R_m Q_m) - P_i h_i R_m Q_m (W + R_i Q_i)}$$

Step4: If $\Delta t_1 > \Delta t$, after time Δt, update the battery capacity information of each user and go back to step 1. Otherwise keep on transmitting till one of the users runs out of battery.

However we can see that if Δt is too small, a lot of re-ordering will be needed. To reduce the number of re-ordering, a threshold τ is introduced. If the value from (11) is less than τ, the value of Δt is set to τ.

3.2.3. Performance comparison

In this sub-section, we compare the averaged minimum transmission time, cell outage probability, total transmission power and number of re-ordering required for different SIC ordering schemes, namely the dynamic ordering, the static ordering, the gain ordering and the conventional rate ordering [3] in which the users are arranged according the descending order of their rate requirement. Path loss, shadowing and Rayleigh fading models are included in the comparison.

We carried out simulation to find the maximum minimum transmission time for a group of users for different schemes. Here we consider a system with three classes of services. The rate and QoS requirements of the services are summarized in Table 1. Users are randomly picked within a uniformly distributed circular cell. Peak power constraints are imposed on the users. For those users whose required transmission powers exceed the peak power constraint, it is assumed that they fail to meet the QoS requirement. The outage probability of the cell is defined as the probability that at least one user in the cell cannot meet the QoS requirement. The parameters used in the simulation are shown in Table 2.

The channel gain of the user in db is given by

$$h = -1.0 \cdot \left(PL(d_0) + 10 \cdot n \cdot \log_{10}\left(\frac{d}{d_0}\right) + X_{\sigma_s} + \gamma \right) \quad (12)$$

where

$$PL(d_0) = 10 \cdot \log_{10}\left(\frac{16\pi^2 d_0^2}{G_t G_r \lambda^2}\right) \quad (13),$$

X_{σ_s} is lognormal shadowing with standard deviation σ_s, γ is the amplitude of a Rayleigh fading channel whose real and imaginary parts have normal distributions with zero

Table 1. Required Performance of Multi-class services

	Information bit rate	Required BER	Required SNR
1	384k	10^{-6}	10.6dB
2	192k	10^{-5}	9.6dB
3	96k	10^{-4}	8.4dB

Table 2. Parameters of the multirate CDMA system

Item	Symbol	Value
Bandwidth	W	5MHz
AWGN spectral density	N_0	$1.38e^{-23} \cdot 300$
Path loss exponent	N	3
Shadowing standard deviation	σ_s	5dB
Rayleigh fading minimum gain	C	0.001
Carrier frequency	f_c	900MHz
Radius of the cell	d_{cell}	500m
Close-in distance	d_0	50m
Maximum allowable received E_b/N_0	Q_{peak}	50dB

mean and variance ½. The minimum gain of rayleigh fading is -30db, i.e., 0.001. We also assume unity gain for the transmit and receive antenna, i.e. $G_t = G_r = 1$.

In this simulation, we use the three classes of services in Table 1. The corresponding peak power is 0.226w, 0.113w and 0.056w. The ratio of the number of type 1, 2 and 3 users is equal to 2, 2 and 2, respectively. We ran simulations for 6, 12, 18 and 24 users, respectively.

For every simulation, we randomly generate the location of each user (d) which is uniformly distributed between 50m to 1000m, the battery capacity (E) which is uniformly distributed between 0 to 1.

The averaged minimum transmission time, the outage probability, the total transmission power and the number of re-ordering required are summarized in tables 3 to 6.

For comparison, we normalize the minimum transmission time of all the schemes by the value obtained for the rate-ordering scheme. Table 3 summarizes the average results over 1000 different simulations.

We can see that the average normalized minimum transmission time increases when there are more and more users in the cell. Given 24 users in the cell, the minimum time can be extended more than 30 times by using static ordering. With dynamic ordering, an additional 17% improvement can be obtained when there are 24 users in the cell. For smaller number of users such as 6, the improvement is reduced to about 3%. Comparing with gain ordering which minimized the total power consumption, both static and dynamic order schemes have significant improvement in extending the minimum transmission time.

Table 4 shows the average outage probability. It can be shown that the outage probability has been reduced using dynamic, static and gain ordering compared with that using rate ordering.

Table 5 summarizes the total transmission power of all the users. The power consumption of both dynamic and static time ordering schemes are higher than that of using gain ordering scheme which has the minimum transmission power. The differences are from 8 to 10%.

Table 3. Average normalized minimum transmission time

No. of users	6	12	18	24
Dynamic	1.95	5.16	14.72	37.35
Static	1.91	4.92	13.58	33.00
Gain	1.60	2.90	4.93	6.77
Rate	1	1	1	1

Table 4. Average outage probability

No. of users	6	12	18	24
Dynamic	4.9e-5	1.09e-4	1.5e-4	7.2e-4
Static	4.9e-5	1.09e-4	1.5e-4	2.2e-4
Gain	4.9e-5	1.09e-4	1.5e-4	2.1e-4
Rate	2.0e-4	1.51e-3	7.4e-3	2.8e-2

Table 5. Average total transmission power in dbm

No. of users	6	12	18	24
Dynamic	2.54	7.18	11.99	18.08
Static	2.52	7.15	11.91	17.87
Gain	2.32	6.57	10.80	16.28
Rate	4.64	11.04	16.63	22.34

Table 6. Average number of re-ordering required

	6	12	18	24
Dynamic	1.23	1.55	2.21	3.47

Table 6 shows the number of re-ordering required for the dynamic ordering scheme.

For comparison, it is better to have a bound of the optimum minimum transmission time. However, it is quite hard to find a tight bound of the maximum minimum transmission time when a group of users suffer from different channel losses and have different rate, QoS requirement and initial battery capacity.

To show the effectiveness of our proposed dynamic ordering scheme, we assume that all the users suffer from the same channel loss and have the same rate QoS requirement and initial battery capacity.

The total transmission powers of different decoding orders are the same under this situation. The optimal ordering scheme should let all the users run out of battery at almost the same time. A tight bound thus can be obtained by dividing the total battery of the users with the total transmission power.

Simulations were carried out where we assume that all the users are transmitting at 192kbps and suffering from the same channel loss and have the same initial battery capacity.

The simulation results are shown in Tables 7 and 8 where I represent the tight bound of the minimum transmission time. We can see that no extension of minimum transmission time can be obtained using static time and gain ordering scheme.

The dynamic schemes are more effective and there is only about 20% degradation comparing to the tight bound. At the same time, the number of re-ordering required increases significantly compared with that shown in table 6.

Table 7. Normalized minimum transmission time under the same initial condition

	6	12	18	24
I	1.86	3.20	4.69	6.23
Dynamic	1.73	2.83	3.98	4.82
Static/gain/rate	1	1	1	1

Table 8. Numb of re-ordering required under the same initial condition

	6	12	18	24
Dynamic	6.98	14.74	22.23	24.65

3.3. Maximize the total transmission revenue

3.3.1. A Simple ordering schemes

Given the rate, battery power capacity and QoS requirements of all the users, we find an ordering scheme to maximize the total revenue which is given by

$$\max\left(\sum_{i=1}^{N} t_i V_i\right) = f\left(E_1, V_1, P_1, \cdots E_N, V_N, P_N\right) \tag{14}$$

subject to the constraints of (3), given that the battery capacity of user i is E_i its charge per minute is V_i and user i will keep on transmitting with a transmitting power P_i until it runs out of battery. From (7), the revenue coming from user *i* before he runs out of battery is

$$\frac{E_i \cdot V_i}{P_i} = \frac{E_i \cdot V_i \cdot h_i}{R_i \cdot Q_i \cdot \prod_{j=i+1}^{N}\left(1+\frac{R_j \cdot Q_j}{W}\right) \cdot N_0} \tag{15}$$

where $\prod_{j=i+1}^{N}\left(1+\frac{R_j Q_j}{W}\right)$ represents the interference coming from the users decoded after him.

When all the users have the same R and Q, (15) is simplified to

$$\frac{E_i \cdot V_i}{P_i} = \frac{E_i \cdot V_i \cdot h_i}{R \cdot Q \cdot \prod_{j=i+1}^{N}\left(1+\frac{R \cdot Q}{W}\right) \cdot N_0} \tag{16}$$

It is clear that for those users with large $E_i \cdot V_i \cdot h_i$, detecting them later can have more gain in terms of the total revenue than detecting those users with small $E_i \cdot V_i \cdot h_i$ later. When R and Q of each user are not the same, from table 1, we can find that the higher the R, the higher the Q. To reduce the interference among a group of users, we should detect the users with high transmitting rate first. As the user with high R may have large $E_i \cdot V_i \cdot h_i$ at the same time, we need different trade off schemes to solve this problem.

Based on the above argument, we propose the following 6 schemes and use simulation to test their effectiveness in increasing the total revenue. These schemes can be divided into two types, P1 to P3 do not use the knowledge of the battery capacity of each user while E1 to E3 use these knowledge.

P1: Let $G_i = h_i \cdot V_i$, the users are detected in descending order of rate. For those users with the same rate, they are ordered according to the ascending order of G_i.

P2: Let $G_i = \frac{h_i V_i}{Q_i R_i}$, the users are detected according to the ascending order of G_i

P3: Let $G_i = \frac{h_i V_i}{Q_i R_i \left(1 + R_i Q_i / W\right)^3}$, the users are detected according to the ascending order of G_i

E1: Let $G_i = E_i \cdot h_i \cdot V_i$, the users are detected according the descending order of rate. For those users with the same rate, they are ordered according to the ascending order of G_i.

E2: Let $G_i = \frac{E_i h_i V_i}{Q_i R_i}$, the users are detected according to the ascending order of G_i

E3: Let $G_i = \frac{E_i h_i V_i}{Q_i R_i \left(1 + R_i Q_i / W\right)^3}$, the users are detected according to the ascending order of G_i

When using these ordering schemes, we also assume that re-ordering would be done only when one of the users runs out of battery, so at most N-2 re-ordering are required if there are N users in the cell.

4. SIMULATION RESULTS

We use a system with similar parameters as that described in section 3.2 except that the ratio of the type 1, 2, and 3 users is 3, 2 and 1.

For comparison, we normalize the total revenue of these schemes with that obtained from a random ordering.

4.1. Maximizing the total transmitting time

We first assume that the normalized charge per minute for type 1, 2 and 3 users are all 1. Thus $\frac{E_i \cdot V_i}{P_i} = \frac{E_i}{P_i}$, and the optimization problem is actually equal to maximizing the total transmitting time with the knowledge of each user's battery capacity.

Table 9 shows the total transmitting time of all the users under different ordering scheme, respectively. Comparing with the results of using random ordering, it can be seen that using scheme P1 and E1 have the biggest improvement. This means that when the charge per minute of each user is the same, reducing the interference coming from those users with high transmission rate can have more gain in total revenue compared with other schemes. The users with high data rate should be detected first.

4.2. Maximizing the total transmitting data

Next we assume that the normalized charges per minute of type 1, 2 and 3 users are 4, 2 and 1, respectively. It is just the same as the ratio of their transmission rate. The problem is equal to maximizing the total number of transmitted data with the knowledge of battery capacity of each user.

Tables 10 summarizes the total transmitting data of the users under different ordering schemes, respectively. Comparing with the results using random ordering, it can be seen that using schemes P3 and E3 have the biggest improvement in revenue. This means that to maximize the total transmitting data, the channel power gain of the user should be weighted with the amount of the interference generated by this user to the others.

4.3. Maximizing the total revenue

Now we assume that the normalized charges per minute of type 1, 2 and 3 users are 16, 4 and 1, respectively. The problem is to maximize the total revenue with the knowledge of battery power of each user.

Tables 11 summarize the total transmitting data of the users under different ordering schemes, respectively. Comparing with the results using a random ordering, it can be seen that using scheme P2 and E2 have the biggest improvement in revenue. This means that as the charge per minute for the high data rate user is increasing, the influence of its interference to others on the ordering is reduced.

4.4. The influence of the user's battery capacity on the total revenue

From the above simulation results, we can see that only a few percentage improvements are achieved with the knowledge of battery capacity of the users. To study the effect of the battery capacity, the user type and the channel gain of each user on the total revenue, we assume the charge per minute of each user is the same.

We first assume that all the users are of type 2 and the channel gain of each user is -20db. The ordering scheme P1 is just the same as random ordering, and the ordering scheme E1 becomes that the users are detected according to the increasing order of E_i. The results are shown in Table 12. We can see that almost 40% increase in the total transmitting time is obtained using the knowledge of the battery capacity of the users.

Next, we assume that the ratio of the number of type 1, 2 and 3 users are 2, 2 and 2, respectively, and the channel gain of each user is still the same. The ordering scheme P1 becomes that the users are detected according to the decreasing order of the rate. The ordering scheme E1 is just the same as the users are detected according to the decreasing order of the rate and the increasing order of E_i. The results are summarized in Table 13. We can see that the difference between using E1 and P1 is quite small.

Finally we assume that all the users are of type 2 while the channel gain of each user is not the same. They are generated according the scheme used in previous sub-section. Using scheme P1, the users are detected according to the increasing order of their channel gain. Using scheme E1, the users are detected according to the increasing order of the channel gain weighted with the battery capacity.

Table 9. Total transmitting time of users

U	O	**P1**	**E1**	P2	E2	P3	E3
6	1	**1.09**	**1.10**	1.06	1.07	1.08	1.09
12	1	**1.15**	**1.16**	1.10	1.12	1.13	1.14
18	1	**1.18**	**1.19**	1.12	1.15	1.16	1.18
24	1	**1.20**	**1.21**	1.14	1.17	1.19	1.20

Table 10. Total transmitting data of users

U	O	P1	E1	P2	E2	**P3**	**E3**
6	1	1.03	1.03	1.04	1.05	**1.04**	**1.05**
12	1	1.05	1.06	1.07	1.09	**1.08**	**1.10**
18	1	1.06	1.08	1.10	1.12	**1.11**	**1.13**
24	1	1.07	1.09	1.11	1.14	**1.13**	**1.16**

Table 11. Total revenue under case 2

U	O	P1	E1	**P2**	**E2**	P3	E3
6	1	0.98	0.99	**1.06**	**1.07**	1.04	1.06
12	1	0.98	0.99	**1.11**	**1.13**	1.10	1.12
18	1	0.98	0.99	**1.15**	**1.17**	1.13	1.16
24	1	0.98	0.99	**1.17**	**1.20**	1.16	1.19

Table 12. Total transmitting time of users with the same R, Q and h

User	P1	E1
6	1	1.12
12	1	1.40

Table 13. Total transmitting time of users with the same h

User	Non	P1	E1
6	1	1.19	1.20
12	1	1.42	1.44

Table 14. Total transmitting time of users with the same R, Q

User	Non	P1	E1
6	1	1.10	1.12
12	1	1.18	1.21

The results are summarized in Table 14. We can again see that the difference between using E1 and P1 is not large. From the above results, we can see that the extra gain in total revenue is only a few percent with the knowledge of the battery capacity of the user when the rate and channel gain of the users are not the same. However, significant improvement in total revenue can be obtained if the channel gain and battery capacity of each user are the same.

4. CONCLUSION

In this paper, we have studied different optimization objectives for the power control of the up-link of CDMA system with perfect SIC. Different ordering schemes, which utilize the knowledge of the battery capacity of the users are proposed. It is shown that the minimum transmitting time of a group of users can be extended significantly using these ordering schemes. We also presented ordering schemes which can increase the total revenue of the system.

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