Downlink Power Control Based on Utility during Soft Handover in DS-CDMA Systems*

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Abstract. In this paper, we propose two downlink power control schemes based on utility  
during soft handover in DS-CDMA systems. Based on two different soft handover algo-  
rithms, we also design two power control schemes during soft handover. Our proposals  
introduce the utility and pricing functions into the downlink power control algorithms  
during soft handover. The goal is to achieve the maximum revenue for handover users.  
Simulation results show that the performance is better when only one base station with  
the best channel gain transmits the users' information.

Keywords: CDMA, soft handover, power control

1 Introduction

Power control and soft handover are two essential techniques which can effectively increase  
the capacity greatly in CDMA systems. As we all know, the CDMA system is interference  
limited. That is to say, the system capacity is limited by the interference. Moreover, in  
CDMA systems, user’s transmit power and data rate are all tunable according to current  
user’s QoS requirements, channel conditions and system load. Hence, the Power control  
in CDMA system aims at minimizing the total interference and soft handover handles the  
mobility issues of the mobile nodes.

In general, power control in CDMA system is needed to compensate for the so called  
near-far problem. In the real application, there are always some mobile nodes being close  
to the base station, while others may be far away. Therefore the power balancing is needed  
in order that the mobile nodes close to the stations may not block the connections of the  
mobile nodes located far from the base station [1].

On the other hand, in order to keep communications when mobile nodes are moving  
from one cell to another, soft handover technique is proposed in CDMA system. During  
soft handover, the mobile nodes may have two or more connections at the same time.

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On the uplink, the mobile nodes receive the signals from all the base stations. This can improve the performance because of the macrodiversity gain. On the downlink, all the base stations independently decode the signal that they have received. Then the base stations send the obtained information to the mobile switching center (MSC) which favors the base station that receives the strongest signals. Some researches have demonstrated that soft handover can result in a larger cell coverage area and a subsequent enhancement on uplink capacity. Other researches have proved that soft handover can be used to alleviate the traffic in overloaded cells [2].

Now there are four typical soft handover algorithms in CDMA systems, which are distance-based soft handover algorithm, IS-95A soft handover algorithm, UTRA soft handover algorithm and SSDT (Site Selection Diversity Transmit) algorithm. However, soft handover could have harmful effect on the overall system capacity. Actually when users are connected to different base stations simultaneously, they are generating more interferences and monopolizing base station power spreading codes by this way. Intuitively, a user during soft handover is more or less stealing some resources from the potentially new users.

During soft handover, the power control procedure is more complicated since there are at least two base stations involved. On the uplink, the mobile node adjusts its transmit power based on the combination of received TPC (Transmit Power Control) commands from all the base stations in the active set. In general, when all the base stations in the active set require larger transmit power, the mobile node will increase its power; however, if only one base station requires smaller transmit power, the mobile node will reduce its power in the next time slot since that reducing the transmit power can minimize interference and extend battery life. Differently, in the downlink direction, only one TPC command is sent by the mobile node. All the base stations in the active set adjust their transmit power based on this TPC command. Therefore the TPC command is very important in this mode. If the command is error, the interferences will increase greatly.

Many downlink power control schemes during soft handover have been proposed in [3] [4] [5] [6] [7]. It is proved that power drifting between base stations can be reduced by changing the way that mobile node transmit the TPC command in [3]. The mobile node repeats the same TPC command over many slots. This results in reducing the times that the base stations adjust their powers and also reducing the errors in the TPC commands. A new optimized power control scheme has been proposed in [4]. According to the downlink qualities of the channels involved in soft handover, the transmit powers of the base stations in the active set are dynamically allocated. This scheme can reduce the additional interference caused by the multiple site transmission during soft handover. In [5], the adjustment loop power control has been proposed to maintain the balance of the transmit power among the different base stations in the active set. 3GPP adopts this power control scheme as one of the downlink power control strategy during soft handover. However, in [6], an unbalanced power control allocation scheme has been investigated and results has shown that it can reduce the overall transmit power. In this scheme, the base station which has a better channel gain will transmit the mobile signals at a higher power. Ref. [7] has proposed a new scheme named SSDT (Site Selection Diversity Transmit) and it is the extreme version of the unbalanced scheme mentioned above. In SSDT algorithm, only one base station with the best channel gain will transmit the users’ information.
All the other base stations in the active set only transmit the control signals. Hence, the interference caused by the multiple site transmission is mitigated. However, SSDT algorithm also loses the benefits of macrodiversity.

In this paper, we propose two downlink power control schemes based on utility and pricing functions during soft handover in DS-CDMA systems. The goal is to obtain the maximum revenue of handover users which can improve the resource utilization. In section 2, We use utility and pricing functions to set up the system model. We introduce the utility functions and describe the utility-based downlink power control problem during handover. Then we research the optimal power allocation by finding the optimum solution in Section 3. In this section, a thorough description of the power control algorithm is given. Section 4 presents the simulation results. Finally we conclude this paper in section 5. The motivation for focusing on the downlink direction is derived from the asymmetric features of 3G Internet and multimedia services.

2 System Model

Both transmit power control and soft handover concern about providing the better QoS for users. However, how to measure the QoS is also an important problem. In fact, QoS itself is a perception which represents the satisfaction level that a user or an upper layer application obtains when using the service provided by the network. The satisfaction level can be measured by the concept of utility.

Economic analysis, involving utility function has been used for understanding performance of wireless networks [8] [9] [10] [11]. In [8] and [9], authors proposed distributed utility-based power control schemes for uplink and downlink in CDMA systems, respectively. Ref. [10] proposed a distributed power control scheme based on a N-person noncooperative game model and showed the conditions for feasibility of such power control as well as existence and uniqueness of the Nash equilibrium achieved by the non-cooperative game. But the resulting equilibrium is shown to be Pareto inefficient. Then in [11], they improved the scheme by introducing cost to utility functions.

The concepts of economic are applied to study distributed power control where users maximize their utility. Generally speaking, power control problem is formulated as a noncooperative game. The game settles at a Nash equilibrium if there exists one. Since users act selfishly, the equilibrium point is not necessarily the best operating point from a social point of view. Pricing the system resources appears to be a powerful tool for achieving a more socially desirable point.

However, the references mentioned above considered only the problem of power control when the mobile nodes are moving in one cell. In fact, almost twenty percent users are during soft handover process in CDMA systems. The power control problem during the soft handover is different from the normal conditions since the mobile node communicates with two or more base stations. In the other hand, the multiple site transmission may cause the additional interference.

This paper takes a different approach to solve the power control problem, by developing a power control scheme based on an economic model specifically for soft handover users in DS-CDMA systems. We believe an explicit economic model can serve as a useful guide in developing a good power control mechanism for the handover users by understanding
the factors that affect QoS. To achieve this, we develop a model to qualify the level of satisfaction experienced by a handover user. How to cooperate the power from different base station is our emphases. For simplification, we consider two base stations during soft handover in this paper.

In a wireless communication system, each user transmits its information over the air using some multiple access system. Since air is a common medium for all the signals, each user’s signal acts as interference to the other user’s signal. Further, because of fading, multipath and other impairments, the radio signal is changed by the time it travels from the transmitter to the receiver. A common method to measure all these factors is the SIR of the received signals.

In this paper, we introduce utility and pricing function, the concept of the economics, to set up the model for power control during soft handover in DS-CDMA systems. We take the transmit power as an important commodity in CDMA systems. Hence, depending on the transmit power and the SIR(signal-to-interference ratio) obtained by the user, we would like to formulate an expression to determine the user’s satisfaction from using the network. Therefore we use utility function to evaluate the user’s satisfaction level and the pricing function represents the cost that user should pay for the occupied radio resources.

Here the utility function of user $i$ is given by $U_i(p_i)$. The form of $U_i(\cdot)$ should be carefully selected in order to properly reflect the nature of satisfaction level. Some researches have pointed out that $U_i(\cdot)$ should be an non-decreasing function, satisfying $U_i(0) = 0$ and $U_i(\infty) = U_{i_{\text{max}}} < +\infty$ [8] [9]. For data users who have no stringent QoS requirements on transmission data rate, we can assume an increasing concave function. For data and multimedia applications which have minimum rate requirements, Sigmoidal-like functions are used.

In a typical wireless communication system, there may be $N$ users and each has its own utility, which depends on SIR received from the base stations and the user’s transmit power. It is evident that as a user tries to increase its power in order to increase its SIR, which causes more interference to other users thereby degrading their performance. Especially during soft handover, one user communicate with two base stations at the same time and the signals from different base stations interfere with each other. Therefore we need to charge the price for using the network. On the other hand, in order to maintain a healthy wireless environment, we also need to charge it for causing harm to other users and other base stations. Hence, the pricing function of user $i$ is given by $C_i(p_i)$. The form of $C_i(\cdot)$ should be a monotonically increasing function of transmit power [10].

3 Finding the Optimal Solution

Consider a typical cell on the downlink of a multimedia DS-CDMA systems with $N$ users. Denoted by $R_i$ the transmission rate, by $P_i$ the transmit power, and by $h_i$ the channel gain from base station to the user $i$. Let $\mathbf{R} = \{R_1, R_2, \cdots, R_N\}$ and $\mathbf{P} = \{P_1, P_2, \cdots, P_N\}$. $W$ represents the system bandwidth and $I_i$ is the background interference at the location of user $i$. Therefore the received SIR of user $i$ is given by:

$$\gamma_i = \frac{W h_i P_i}{R_i \theta_d h_i (\sum_{j \neq i} P_j) + I_i},$$

(1)
where \( \theta_d \) is the downlink orthogonality factor with the typical values falling in the range of \((0.1, 0.6)\).

We define the user’s revenue as the difference of utility and cost. Hence, maximizing the revenue is our target. Mathematically, our power control problem is formulated as an optimization problem aiming at finding the user’s maximal revenue. Based on two different soft handover algorithms, we also design two power control schemes during soft handover as following.

### 3.1 Scheme 1: U-TSTS (Utility based Two Sites Transmission Simultaneously)

In this scheme, the mobile node connects with two base stations simultaneously during soft handover. The mobile node receives signals from two base stations and transmit informations to them. Therefore the QoS of received signals are determined by two base stations. How to allocate the transmit power between two base stations is an important issue. Since the power of two base stations may interfere each other, we must select the proper transmit power for each base station to achieve the maximum revenue for the user.

From (1), we get the SIR received by the mobile node from two base stations respectively:

\[
\gamma_1 = \text{sir}_1 = \frac{W p_1 h_1}{R p_2 h_2 \theta + I_0},
\]

(2)

and

\[
\gamma_2 = \text{sir}_2 = \frac{W p_2 h_2}{R p_1 h_1 \theta + I_0},
\]

(3)

where \( I_0 \) is the background interference.

In this scheme, the mobile node gets the utility from two base stations and pays the corresponding cost to both of them. We define the utility as the function of SIR and define the pricing as the function of transmit power. Taking the channel gain as a parameter, the utility is also the function of transmit power. Therefore the user’s total utility is the summation of the utility obtained from two base stations, which is same to the user’s total cost. Our target is to maximize the user’s revenue. Therefore, the power control problem during soft handover is expressed as following:

\[
\max_{p_1, p_2} U(\gamma_1) + U(\gamma_2) - C(p_1) - C(p_2).
\]

(4)

From the first order necessary optimality conditions, \( U'(\gamma_1) + U'(\gamma_2) - C'(p_1) - C'(p_2) = 0 \), we get \( p_1^* \) and \( p_2^* \), which are the optimum solution of this problem. In our power control scheme, the mobile node pursues the maximum revenue of itself. However, the existence of pricing for users may make more efficient use of system resources and cause users to act in a more socially acceptable manner.
3.2 Scheme 2: U-SSDT (Utility based Site Selection Diversity Transmit)

This scheme is based on SSDT algorithm, which has mentioned in the section 1. The SSDT power control algorithm enables user select transmission site dynamically during soft handover. The capacity improvement of SSDT is due to the mitigation of multiple site transmission and the increased path capturing efficiency at RAKE receiver. However, how to select the best transmission base station, which is called primary BS, is still a noticeable issue. Our basic idea is to choose the "primary BS" by using utility and pricing functions. That is to say, the mobile node would like to select the base station which can bring out the maximum revenue for the user, as the "primary BS".

Since in SSDT algorithm, only one base station transmits user’s information at one time slot, the interference caused by other base stations can reduce to zero. Therefore the SIR received by the user from two base stations separately are:

\[
\gamma_1 = \frac{Gh_1 P_1}{I_0},
\]

and

\[
\gamma_2 = \frac{Gh_2 P_2}{I_0},
\]

where \( G = \frac{W}{(R \ast \theta)} \)

The optimal problem is:

\[
\max_{p_i} U(p_i) - C(p_i).
\]

From the first order necessary optimality conditions, \( U'(p_i) - C'(p_i) = 0 \), we get \( p_i^* \) and \( p^*_2 \), which are the optimum solution of this problem. Comparing the two maximum revenues, the user will choose the base station which can achieve larger revenue as the primary BS. On the other hand, the pricing function contains alterable parameters, which should vary with the utilization of the resources in the base stations. That is to say, the pricing function can respond the system load. If the load is heavy, the price is high and vice versa.

3.3 Formula Deduction

As we all know, if \( U'(p_i) \) is a monotone decrease function and \( C((p_i) \) is a linear function, the feasible solution of proposed problem is existence and uniqueness. For simple, we assume a linear function \( C(p_i) = \lambda_i p_i \), and the utility function \( U(\gamma_i) = \ln(1 + \gamma_i)^a \), which is a monotone increase function. And \( U'(\gamma_i) \) is a monotone decrease function. So we can ensure that the solutions of equation (4) and (7) are existence and uniqueness. On the other hand, the parameters \( \lambda_i \) change with the system load and can adjust with our targets. By mathematical operating, we get the results.

U-TSTS algorithm:
\[
\frac{a}{1 + \gamma_1} = \frac{(\lambda_1 \gamma_2 + \lambda_2 G)(G + \gamma_2)G I_0}{(G^2 - \gamma_1 \gamma_2)^2} 
\]

\[
\frac{a}{1 + \gamma_2} = \frac{(\lambda_2 \gamma_1 + \lambda_1 G)(G + \gamma_1)G I_0}{(G^2 - \gamma_1 \gamma_2)^2}. 
\]

U-SSDT algorithm:

\[
\max_1 = \ln\left(\frac{aGh_1}{\lambda_1 I_0}\right) - \frac{\lambda_1 I_0}{Gh_1} - a, \quad p^*_1 = \frac{aGh_1 - \lambda_1 I_0}{Gh_1 \lambda_1} 
\]

\[
\max_2 = \ln\left(\frac{aGh_2}{\lambda_2 I_0}\right) - \frac{\lambda_2 I_0}{Gh_2} - a, \quad p^*_2 = \frac{aGh_2 - \lambda_2 I_0}{Gh_2 \lambda_2}. 
\]

The results of U-SSDT algorithm are explicit expression while the results of U-TSTS algorithm are implicit expression. Therefore, we can use the simulation to compare these two schemes.

### 4 Numerical Results

In this section we present the numerical results. We simulate two typical cells in DS-CDMA systems. In this system, the mobile node connects with two base stations at the same time during soft handover. The mobile node moves randomly in the boundary of the cells. Other system parameters are assumed to be: \( W = 5 \text{MHz} \), \( R = 64 \text{bps} \), \( \theta = 0.4 \) and \( I_0 = 2.5e - 6 \theta \).

Fig. 4 shows the variety of SIR received by the mobile node from two base stations during simulation. Due to the variety of pathloss, the channel condition changes with the time. Fig. 2 is the maximum revenue of proposed two schemes. This figure shows that the maximum revenues of U-TSTS and U-SSDT schemes are the same. That is to say, when only one base station transmits the informations, the user’s revenue reaches maximum in U-TSTS scheme. This conclusion is shown explicitly in fig. 3. This figure is the revenue variety with the power of two base stations. We can see clearly that the maximum is in the boundary. That is to say, the user’s revenue reaches maximum when only one base station transmits information to the user and the transmit power of another base station is zero. This is because that when only one base station transmits information, the interference cause by other base station reduces to zero. In this condition, the user’s revenue achieves maximum. Therefore we think that the U-SSDT scheme is better since it is simple and efficient.

Aiming at different services, such as data or voice, we can select different utility functions. Hence, we can realize the soft handover of multimedia services in CDMA systems. On the other hand, by adjusting the parameter of pricing function, we can achieve other goals, such as load balance, resource reservation, and so on.
**Fig. 1.** Comparison of SIR received from two base stations

**Fig. 2.** Max revenue of propose schemes

**Fig. 3.** Maximum of scheme 1 in 3D
5 Conclusion

In this paper, we have proposed two downlink power control schemes based on utility and pricing function during soft handover in DS-CDMA Systems. The goal is to achieve the maximum revenue of handover user. Based on different soft handover algorithms, we designed two power control schemes: U-TSTS and U-SSDT. Simulation results have shown that our schemes are efficient and flexible. Comparing two schemes, we find that U-SSDT algorithm is better than U-TSTS algorithm.

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