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Improving the Performance of CDMA Mobile Network Using Adaptive Power Control Techniques

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ABSTRACT

The capacity of Code Division Multiple Access (CDMA) technologies used in Wireless mobile networks relies on efficient power control algorithms due to near-far effect. In this work, the performance of the current power control algorithms is first investigated and then a new adaptive power control algorithm for CDMA mobile networks is proposed. The proposed algorithm is able to significantly decrease the variance of the power control maladjustment without any increase in power control signalling; only one bit is still needed for the power control feedback command. Moreover, it is able to minimize mobile station total transmission power which the conventional fixed step power control algorithms fail to handle. In this work, Simulation was carried out for the modified adaptive power control algorithm using MATLAB. Simulation result shows that the Modified Adaptive Power Control (MAPC) algorithm reduces drastically the mobile stations' transmit power which in turn improves the capacity of CDMA mobile network, thanks to its tunable parameters.

Keywords: Power control, adaptive power control algorithm, transmission power

Introduction

In wireless code-division–multiple–access (CDMA) spread spectrum systems, multiple users are allowed to use the same bandwidth at the same time with different codes. Hence the signals from other users are regarded as interference as seen from base station while trying to extract data from a specific user's signal. Since users closer to BS have greater received signal at the BS, this can lead to large interference for users located farther away from the BS. This leads to a problem known as near-far effect. It is more crucial and sensitive on the uplink in the sense that power levels received at the base station from different mobile users should be roughly equal, so that no single mobile user can dominate and prevent recovery of signals from other mobile users. In this work, we concentrate on the study of power control for uplink. **T**he requirement of power control (PC) in the uplink code-division multiple-access (CDMA) system is a critical limitation [1]. Power control is needed because all users share the same bandwidth and thus intra-user interference is bound to occur. Without power control, a signal received by the base station (BS) from a nearby mobile station (MS) will dominate the signal from a far-away MS, thus resulting in the so-called *near–far effect*. The objective of power control is to control the transmitted power by the mobile users so that the average power received from each user is generally constant. The goal is more precisely stated as to achieve a certain Signal-to-Interference Ratio (SIR) regardless of channel conditions while minimizing the interference and hence improving the overall performance. Many schemes have been suggested for power control in uplink channel which generally offer a strategy for transmit power of users to reduce interference and enhance battery life while maintaining data rates required for Quality of Service.

In 3G systems, wideband CDMA has been chosen because theoretically it can provide higher capacity compared with FDMA and TDMA schemes [1]-[2].

However, in order to achieve this "promised" high capacity, good techniques are needed to overcome several wireless impairments. This is why significant research works are currently being devoted to improve the performance of CDMA systems, such as interference cancellation or multiuser detection, smart antennas and power control, to name but a few. Among these areas of research, power control is the most crucial aspect because it plays an important role in a CDMA system [3]. In practical CDMA systems, power control is a fixed step-size algorithm where transmission power will either increase or decrease by a fixed step-size usually 1dB. This approach, although is simple to implement, has invariant adjustment amplitude and hence is not capable of tracking rapid changes in radio channel efficiently. Since the fixed step size power control technique lacks the ability to track the significant changes, hence the MS transmit power is controlled ineffectively leading to high variance of the transmitting power. Other mobiles, consequently, have to increase their transmit power to compensate the power variation. As a result of the increasing power, the total interference in the system will also increase. This situation significantly reduces the system capacity as WCDMA systems are interference limited. On the other hand, when the quality of the

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radio channel elapses the deep fading, the mobiles under this channel should decrease their transmit power in order to minimize the total interference. However, in such rapid change situation, changing the transmit power by fixed step size of 1 dB is not fast enough to decrease the transmit power, resulting in excessive interference to other mobiles. Hence, an efficient power control method with an adaptive PC step size can mitigate such problem and in turn improve the system performance.

II RELATED WORKS

S. Ariyavisitakul in [4] presented the fixed step power control (FSPC) algorithm which can be described with the following steps;

- The base station estimates the received SIR from a particular mobile.
- The estimated SIR is compared with the corresponding SIR target.
- If the estimated SIR is lower than the target, then the base station sends an "up" TPC command. Otherwise, a TPC "down" command will be sent.

The mobile station obeys the command by increasing or decreasing the transmit power based on a fixed step size typically 1 dB. The transmitted power will always change even when there is no change in the channel and this causes oscillations with high variation around the SIR_{target} in a slow-varying radio environment. In addition to this, when the channel changes rapidly, the fixed step size is unable to adequately control the power to compensate the changes.

In [5] P. Taaghol Presented Speed Adapted Closed-Loop Power Control (SA-CLPC) which is an adaptive power control algorithm in which the step size was selected based on user speed estimation. The idea was based on the hypothesis that there is an optimum fixed step size for each of the user speed. This algorithm requires an accurate speed estimator to be installed at the UE. The estimated speed was then used to select the optimal step size corresponding to the UE speed based on a lookup table. Although the performance of SA-CLPC relies significantly on the speed estimator, the author showed that it was not critical to know the exact speed. It could work as long as the user speed could be correctly categorised into a speed range. This work also showed that the performance of SA-CLPC with imperfect speed estimation preformed very similar to that obtained by perfect speed estimation.

The performance of closed-loop power control can be improved by using a linear prediction of power control command bits at the base station as presented in [6]. Hence with the cost of a more complex receiver, we can mitigate the effects of transmission errors of control bits and delays related to generation and transmission of these bits. A linear predictor filter could be used at the receiver with the accumulation of power control bits as input and returning the executing power control according to the predictor output. Linear predictor's performance depends on the autocorrelation of its input, which the authors have shown to have the same autocorrelation properties as of a signal under fading conditions with a bandwidth defined as Doppler spread.

Another method to increase the adaptive ability of power control to reduce the oscillations when the received SIR gets closer to the SIR_{target} was proposed in [7].This method reduces the step size when the difference between the received SIR and SIR_{target} is low, and increases when the difference is high. However, three bits were needed to transfer the required information between base station and mobiles, which required higher bandwidth for information feedback than in 3rd Generation Partnership project (3GPP) specification if it is operated on 1500Hz basis.

In this work, an adaptive power control algorithm based on step size algorithm is proposed to increase the system capabilities. The adaptive method can adjust the step dynamically according to the characteristic of fast fading channel thus gain better control effect. This algorithm calculates step-sizes based on power control command (PCC) history. A CDMA based mobile network in Nigeria (Multilinks Nigeria limited) was used as a case study for the analysis of the system.

III METHODOLOGY

A) Experimental Test bed

This research investigates the performance of adaptive power control algorithms using an experimental setup that involves the use of hardware as test bed to collect real data measurements of the received signals at the base station. In this way, a more realistic and accurate description of the signal environment surrounding the data analyser is used to provide the input for the Adaptive Algorithms being investigated. The experimental test bed consists of three parts: The transmitter (mobile station), wireless channel and receiver (base station). The signal is generated and transmitted wirelessly by the transmitter operating at the 916MHz. The receivers are situated vertically in order to receive the incoming signal and perform down conversion. The information signal is then captured using a data analyzer and subsequently uploaded to a PC for post processing using MATLAB platform. Power control data were obtained from Multilinks Nigeria limited which is used as a case study in this work.

The different sections that make up the experimental testbed are described in this section. The sections include: mobile station, base station, Data analyzer and a PC equipped with MATLAB tool.

MOBILE STATION

The mobile station sends the signal generated to the transmitter (base station) via a transmitting antenna which converts the signal to electromagnetic waves for transmis-

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sion through a wireless medium. This occurs in the uplink while in the downlink, the mobile station receives the transmission power control update step (TPC) which has been adaptively selected by the base station, it then either increases or decreases its initial mobile transmit power based on the power update requirement it receives.

BASE STATION

The receiving antennas receive the electromagnetic waves, convert the signal into electrical signals and send it to the receivers. Adaptive transmission power control is based on the signal-to-interference ratio or SIR measurement value. SIR is measured by the RAKE synthesis of inverse-spread signals at the base station, and the base station compares SIR_{est} with SIR_{target} and generates TPC commands according to the following algorithm: a TPC command is issued to the portable unit to reduce the transmission power whenever the measurement value is larger than the target value. In the opposite case, a command to increase the transmission power is issued. The portable mobile terminals receiving such commands control transmission power accordingly. The TPC is saved in a command register of one bit. For each mobile, RRC layer in the core network sets SIR_{target} based on the system load, the service type and radio interface characteristics. The base station sends a power control message (TPC bit) to the mobile station in each timeslot to request the mobile station to either decrease or increase the transmit power. Parameters are sent to mobile stations via signalization channels. By realizing this operation at the extremely high speed of once every 0.625 ms, transmission-side power control can eliminate fading-induced fluctuations in the reception level and also make it possible to minimize transmission power.

DATA ANALYZER

The data acquisition hardware is used to interface the receivers and the data acquisition tool of the PC. The interfacing module used acquires the data from the received electrical signal and uploads the signal into the PC for analysis. The received signal is then captured using the data acquisition hardware (PCI Module) and uploaded to the PC for analysis on MATLAB. The Reception of the transmitted signal required the receivers and the receiving antennas all operating at 916MHz.

B) Adaptive Power Control Model

Consider the FSPC [4] and DCPC [8] algorithms. For a particular user, these algorithms are described by (all variables in decibel scale)

$$p(t+1) = \min\{p_{max}, p(t)\} + \delta_e \qquad (1)$$

And

$$P(t+1) = \min\{p_{max}, p(t) + \delta sign(e(t))\} \qquad (2)$$

Respectively, where $e(t) = \gamma^t(t) - \gamma(t)$ is the power control maladjustment (error between measured SIR $\gamma(t)$ and SIR target $\gamma^t(t)$) at time instant *t*. The FSPC is used in DS-CDMA systems in practice, since the power update rate is relatively high, and thus the number of bits per power control command must be low so that the power control signalling would not consume too much radio resources. For example, in UMTS the power update rate is 1500 Hz and only up-down commands are used so that only one bit is needed for the command transmission.1

Note that if $\delta = 1$, then $e(t)$ in the DCPC case can be regarded as the power update adjustment that would guarantee that $e(t+1) = 0$ if the channel were static and all other users in the system did not update their powers. The idea of the proposed scheme is to allow the use of an Information Feedback-type algorithm, like the DCPC algorithm, while still employing decision feedback. Thus, the adaptive step size can be thought as a reconstruction of $e(t)$, constructed from the received PC commands $u(t)$, $u(t-1)$...

where $u(t) \epsilon \{-1,1\}$ $t = 0, 1, 2....$

C) The Adaptation method

The adaptation method proposed here is referred to as the *Adaptive Step* (AS) method. Let $e(t) = \gamma^t(t) - \gamma(t)$ and $u(t) = \text{sign}(e(t))$. Then we define the following parameter

$$a(t,x) = \frac{1}{2}[1 + xu(t)u(t-1)] \qquad (3)$$

$x \epsilon \{-1,1\}$

Note that

$$a(t,1) = \begin{cases} 1, & if\ u(t)=u(t-1) \\ 0, & if\ u(t)\neq u(t-1) \end{cases} \qquad (4)$$

And

$$a(t,-1) = \begin{cases} 0, & if\ u(t)=u(t-1) \\ 1, & if\ u(t)\neq u(t-1) \end{cases} \qquad (5)$$

The AS method can be described by

$$\bar{e}(t) = a(t,1)\bar{e}(t-1) + \delta_e u(t) \qquad (6)$$

Where $\bar{e}(t)$ is the reconstruction of $e(t)$ and δ_e is a parameter controlling the speed of the update. While not readily seen from equation (6), the idea of the adaptation method is very intuitive: if the two latest commands have the same sign, the reconstruction of $e(t)$ is updated by δ_e to the direction of the last command $u(t)$ so as to increase the step size of the next power update. If the two latest commands have different signs, a zero crossing must have happened in the signal $e(t)$ and the reconstruction also crosses zero.

The Adaptive Step Power Control (ASPC) algorithm

The ASPC algorithm is simply the combination of the FSPC algorithm, the AS method, and the DCPC algorithm. Considering uplink, the base station generates the commands $u(t) \epsilon \{-1,1\}$ as in the FSPC algorithm; the commands are transmitted to the mobile station, which applies AS to generate a reconstruction $\bar{e}(t)$ of the PC maladjustment, and then updates its power as in the DCPC algorithm, but using the reconstructed value instead of the true $e(t)$. This is described by

$$P(t+1) = \min\{p\max, p(t) + \delta_e(t)\} \qquad (7)$$

The performance of the AS method naturally depends on the selection of the parameter δ_e. If too small δ_e is selected, then the reconstruction cannot track the actual mal-

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adjustment e(t). This can happen for example during a deep fade in the radio channel. On the other hand, if δ_e is too big, then the advantage of the "fine-tuning" provided by the adaptation method to the power control algorithm is significantly reduced. To circumvent these problems, some modifications are proposed to the standard AS method. All these modifications aim to make the parameter δ_e to adapt to various conditions.

An intuitive method to adapt the update parameter is described here. Consider the FSPC algorithm in (2). Since the PC step δ (not to be confused with δ_e) is fixed, the best situation is achieved when the commands (power updates) generated by the FSPC algorithm are consecutive +1's and -1's, since in this case the PC maladjustment e(t) oscillates between the opposite sides of the origin at consecutive samples. The amplitude of this oscillation depends on the step size δ. Now, consider that we could decrease the step size applied at the transmitter, while maintaining the consecutive up-down command flow. In this case the amplitude of the oscillation of the PC maladjustment would be decreased. If the continuous up-down command flow breaks, the step size could be increased again. This modification is called the modified adaptive Step. It is described by:

$$\bar{e}_G(t) = a(t,1)\ \bar{e}_G(t-1) + \delta_e(t)\,u(t) \qquad (8)$$

$$\delta_e(t) = \delta_e(t-1) + \delta_G u(t)\,u(t-1) \qquad (9)$$

Where δ_G controls the rate of change of the update parameter δ(t), which is now time-varying. The idea behind this method is that the update parameter is decreased every time the two most recent PC commands have different signs, otherwise it is increased. In this way the algorithm tries to find the smallest update step size that still leads to consecutive up-down PC command flow. To prevent the update step size from growing too large, it should be limited. A limit of 1 dB was used in all the simulations. The cell load is given as the number of mobile users per cell at a given instant of time. The reason for adapting the step size in the first place is to make the transmission power to change faster if the consecutive TPC commands have the same sign. One can propose the following general adaptive PC algorithm for this purpose as:

$$\bar{e}(t) = c(t)\bar{e}(t-1) + d(t) \qquad (10)$$

$$P(t+1) = p(t) + \bar{e}(t) \qquad (11)$$

IV IMPLEMENTATION

In the existing power control algorithms, a mobile can only request a power decrease or increase from its base station. However, the mobile cannot inform its server that its SIR_{est} is very close to SIR_{target} and that the power must be stabilized. Thus, SIR_{est} can oscillate even if the radio interface parameters are stable. Our proposed algorithm adds some intelligence to the receiver in order to ask the transmitter to stabilize its power. Unlike the algorithms of [7], [8], [9], [10], the proposed algorithm does not need more TPC bits than the conventional UMTS power control algorithm. This proposed method is a modification to the existing adaptive step size power control algorithm so as to increase its performance without any increase in the signalling bandwidth used for feeding back the power control commands. The aim of the Modified Adaptive Power Control (MAPC) algorithm is to reduce the oscillation variance around the SIR_{target}, to cope with channel high fluctuations and to reduce power consumption of the mobiles. The MAPC algorithm adds some intelligence to the principle of adaptive-step power control algorithms so as to minimise oscillations. The MAPC algorithm uses an adaptive power control step in which the parameter δ_e (which controls the speed of the update) is adaptive so as to mitigate the impact of the radio interface variation and hence the system capacity is maximized. All these modifications aim to make the parameter δ_e to adapt to various conditions. Moreover, when SIR_{est} of a mobile is compared with the SIR_{target} and the base station generates an alternative TPC sequence (up and down). Consequently, the base station reduces the power step dedicated to the MS which stabilizes the MS transmit power and hence power consumption is reduced. Nevertheless, we show by simulation that this modified adaptive method increases the system capacity and also reduces the power consumption of the mobiles. Moreover, the tuned parameters of the adaptive schemes offer to the system a degree of flexibility in order to accommodate different mobility types. The following data shown in Tables 1 and 2 were obtained from already measured values of an existing CDMA network in Nigeria.

Table 1: Power control parameters

MS parameters	
SIR_{target}	5 dB
Data rate	12.2 kbps
Maximum Tx power	24 dBm
Speed	3 m/s
Voice activity factor	80%
BS parameters	
Receiver thermal noise	-113 dBm
Cell size	400 m radius
Chip rate	3.84 Mcps
Carrier frequency	1.9 GHz

Table 2: MS transmit power received at the base station at different times

Time t(s)	MS transmit power P_t (dB)
5	-44.793582363
10	-46.523517225
15	-43.386913878

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20	-45.658505030
25	-46.295746621
30	-49.450105658
35	-53.477138605
40	-39.645475634
50	-36.563732988
60	-39.788887376

Source: Multilinks Nigeria limited

Table 3: Power control parameters

parameters		*values*
$\delta = d$	Power control step size	*1*
δ_e =k	Error signal threshold for switching to backup controller / power control update parameter	*0.1*
δ_g = c	variable gain up-date parameter	*0.01*
u (t)	Process input at time instant *t*	*1*
t	*Time*	*0,1,2,3 ...*

The mean transmitted power is averaged over the simulation period. We then analyze the performance of the Fixed Step Power Control (FSPC), the Adaptive Step Power Control (ASPC) and the Modified Adaptive Step Power Control (MAPC) algorithms in a discrete-time simulation with mobility and mean call duration of 60s. This algorithm is characterized by its ease of computation, simplicity in implementation.

V SIMULATION AND RESULT

In simulating the modified adaptive step power control algorithm for enhancing the performance of CDMA mobile network, the main aim of achieving the goal is to monitor the interference levels of all the mobile users in the network. In the beginning of the simulation, a randomly selected user, initially connected to the central cell, is selected for observation and its velocity is set to 3m/s. Each user except the observed user is power controlled using the FSPC, ASPC and MAPC algorithms.

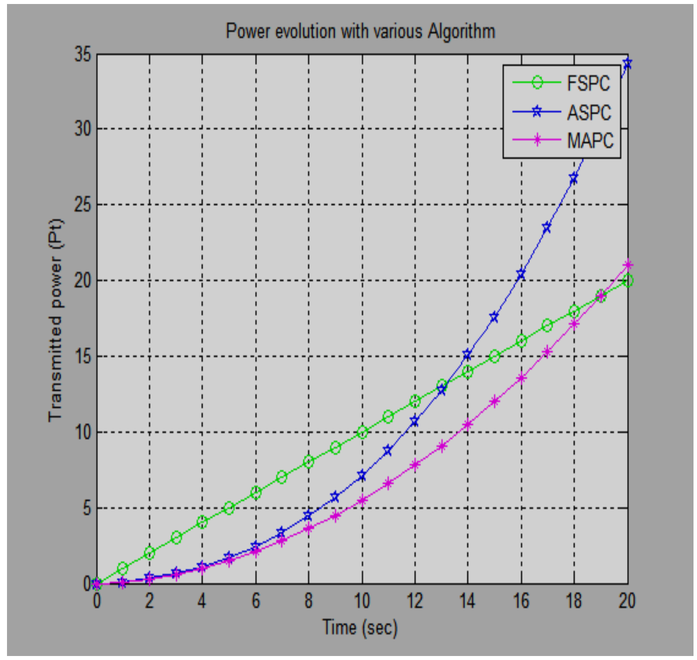

Figure 1 Power evolutions with the various algorithms

Figure 1 shows the power evolution graphically with the parameters that were selected using simulation experiments to give reasonable performance. In the case of FSPC algorithm, the speed of change in the transmission power is linear, while for the ASPC algorithms it is quadratic while for the MAPC algorithm it is cubic. Hence it can be seen that the rate of change in the transmission power with the MAPC algorithm is much better than the other power control algorithms because the mean power consumption is reduced and hence more users can be accommodated.

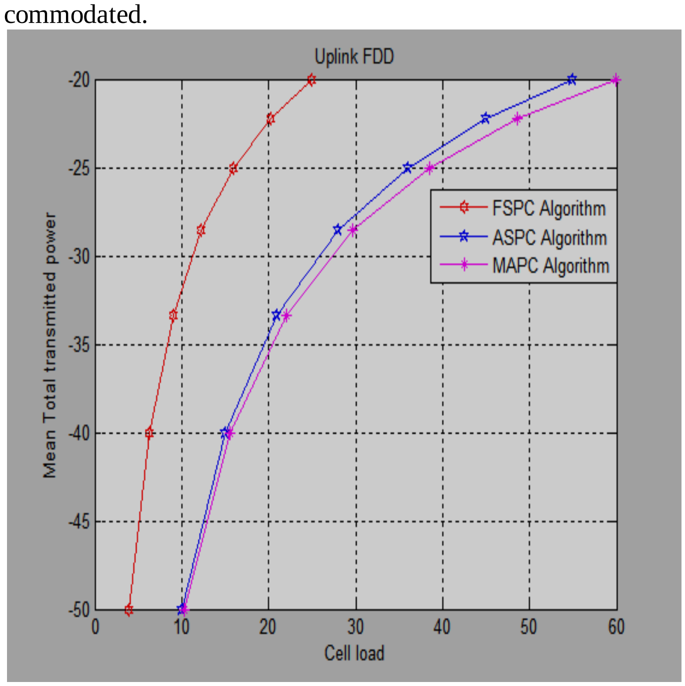

Figure 2 Plot of the mean transmitted power as a function of the cell load for the various power control algorithms

In figure 2, the mobile transmitted powers in uplink are plotted as a function of cell load. The figure shows that the MAPC algorithm reduces the mobiles transmitted powers in the uplink of at least 1 dB from the best configuration of the ASPC algorithm for high loads and more than 12 dB from the best configuration of the FSPC algorithm. This power decrease is the result of decreased amplitude of the oscillation of the PC maladjustment which is achieved by adapting the update step parameter. Furthermore, the power increase in adaptive algorithm is a convex function of cell load while it is a concave function in the FSPC algorithm; therefore, the convergence of total MS transmitted powers to the maximum allowed power is slower in adaptive algorithms. In a dynamic system where path gains are not fixed and where the instantaneous cell load is variable, the mean power consumption is thus reduced by adaptive algorithms. It should be noted also that the adaptive algorithms always have power consumption lower than the FSPC algorithm. In conclusion, these results show that the Modified Adaptive Power Control (MAPC) algorithm is advantageous to CDMA systems thanks to its tuneable parameters. These parameters can be fixed by the network planning tools for different type of user mobility.

VI CONCLUSION

This work presents adaptive power control technique which has gained importance in wireless mobile communication system due to its ability to minimize MS transmit power thereby reducing co-channel and adjacent channel interferences. In this work the modified adaptive step power control algorithm have been studied. The proposed algorithm which clearly has some interesting properties compared to the fixed step size method is a simple variant of the adaptive step size power control algorithm that is able to significantly decrease the variance of the PC maladjustment without any increase in power control signalling; only one bit is still needed for the PC feedback command.

The goal of the Modified Adaptive step Power Control (MAPC) algorithm is to minimize total transmission power which in turn maximizes the system capacity of CDMA system. The Modified Adaptive Power Control (MAPC) algorithm has shown better performance than the Fixed Step Power Control (FSPC) and the Adaptive Step Power Control (ASPC) algorithms; in that system maximum capacity was increased and the power consumption of mobiles has been reduced dramatically. Thus, Adaptive power control has proved its benefits for cellular networks and plays a vital role in next generation networks. For today's broadband era which is highly populated and expected to support different demands of users with the restriction of limited bandwidth, Adaptive power control is a good candidate which fulfill user demands with efficient spectrum utilization.

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