A New Adaptive Power Control Algorithm for UMTS

Rachod Patachaianand, Kumbesan Sandrasegaran
Institute of Information and Communication Technologies and Faculty of Engineering
University of Technology Sydney (UTS)
Email: Rachod.Patachaianand@student.uts.edu.au, kumbes@eng.uts.edu.au

Abstract

The capacity of Wideband Code Division Multiple Access (WCDMA) technologies in Universal Mobile Telecommunication System (UMTS) relies on efficient power control algorithms. The typical UMTS power control algorithm is based on fixed step size. Therefore, it causes oscillations when the radio channel is unchanged. Furthermore, it lacks abilities to cope with rapid variations in fast fading channels. In this paper, we propose a new adaptive power control algorithm for in UMTS. The proposed algorithm can mitigate the oscillations when the channel changes slowly. Moreover, it is capable for tracking rapid changes in fast fading channels, where the typical UMTS power control algorithm fails to handle.

1. Introduction

Universal Mobile Telecommunication System (UMTS) is based on Wideband Code Division Multiple Access (WCDMA) technologies, capable for delivering high data rate services. All users in WCDMA systems share the entire radio channel, e.g. 5MHs for UMTS. However, when the number of users increases, the capacity will be decreased because the capacity of WCDMA systems is interference limited. Therefore, it is important to minimise the interference in the systems. One of the critical sources of interference is transmission power from other users in the uplink (mobiles to base stations). If the transmission power in the uplink is not properly controlled, a mobile close to the base station may transmission excessive power causing large interference to other users connecting to the same cell. This situation significantly reduces the system capacity. Hence, a mechanism to control the transmit power is vital for UMTS.

Power Control is a mechanism responsible for ensuring that the transmission power from and to all entities in the system are just enough for maintaining the minimum SIR requirements of all connections. With an ideal power control mechanism, each mobile in the uplink will transmit the minimum power to achieve its minimum SIR requirement. The minimum transmitted power means the interference is minimised. The system capacity is, thus, maximised.

In this paper, we study adaptive power control algorithms used in UMTS. Different power control currently used in UMTS will be overviewed in section 2. The adaptive power control algorithms proposed in other works and our adaptive algorithm, are discussed in section 3. The model and assumptions used in the simulation are explained in section 4. The simulation results are presented in section 5. Section 6 concludes this work.

2. Power Control in UMTS

Power control in UMTS can be widely classified as two types: open-loop power control, and closed-loop power control. The open-loop power control is employed at the beginning of a connection, and an uplink Dedicated Channel (DCH) or Common Packet Channel (CPCH), is not yet allocated. With this power control technique, the mobile initially adjusts the uplink power to be transmitted according to the power received from the base station. After that, closed-loop power control will be applied. This paper focuses on closed-loop power control techniques used in the uplink UMTS.

UMTS Uplink Closed-loop Power Control

Closed-loop power control procedures in UMTS are standardised by 3GPP [9]. The closed-loop power control can be further divided into two processes: outer-loop power control and inner-loop power control (also called fast closed-loop power control).

Outer-loop Power Control

The outer-loop power control is responsible for adjusting the SIR target, based on some particular measured parameters such as BLER. The required BLER depends on both radio conditions, and service types. The individual SIR target of each mobile will be set according to such conditions and service types. A connection under poor radio conditions, such as when the mobile moving quickly resulting in rapid changes of radio channel, may require higher SIR target than the one moving slowly. In addition, different service types require different BLER, e.g. data services usually require lower BLER than voice services. As a result, the SIR targets of data services are higher than of voice services.

The outer-loop power control will adjust the SIR target until the BLER requirement of individual connection is achieved. The frequency of SIR target updating is 10-100 Hz [1].

Inner-loop Power Control
Inner loop power control mechanism adjusts the transmitted power to maintain the received SIR equal to the SIR target. In 3GPP specifications, WCDMA frame length is 10 ms. Each frame consists of 15 time slots. Each time slot contains one bit of power control command[1], called "Transmit Power Control", TPC. This result in 1500 Hz of the closed loop power control frequency. The bandwidth of 1.5 kbps is dedicated to fast closed-loop power control feedback.

Two inner loop power control algorithms were purposed in 3GPP specification [9]. The first algorithm updates the transmit power every time slot, while the second updates the power every five time slots. Only the first algorithm is considered in this work.

The 3GPP inner loop power control procedures can be described as the following steps:

1) The base station estimates the received SIR from a particular mobile.
2) The estimated SIR is compared with the corresponding SIR target.
3) If the estimated SIR is higher than the target, then the base station sends an "up" TPC command. Otherwise, a TPC "down" command will be sent.
4) The mobile station obeys the command by increasing or decreasing the transmit power based on a fixed step size, typically 1 dB [1].

The closed loop power control algorithm used in UMTS in a fixed step size power control (FSPC) algorithm. The updated transmit power can be represented as:

$$P(t+1)=P(t)+\delta \cdot sign(SIR_{target}-SIR_{est}) \text{ [dB]}^2 \quad (1)$$

when $P(t)$ represent the transmit power at time t, δ is the power control step size, SIR_{target}, and SIR_{est} is the SIR target, and the estimated SIR, respectively. *sign* is the sign function: $sign(x) = 1$, when $x \geq 1$, and $sign(x) = -1$, when $x < 1$.

It can be noted that $sign(SIR_{target}-SIR_{est})=-1$ is equivalent to a TPC power up command which can be represented by bit 0.

From Equation 1, on every time slot, the transmit power will be increased or decreased by one power control step size. It can be observed that the transmit power must be increased, or decreased in every time slot. Therefore, the transmit power will be always changed even when there is no change in the channel. This situation results in oscillations in a slow-varying radio environment.

[1]Redundant bit can be added with the purpose of error protections.

3. Adaptive Step Size Power Control

The 3GPP specification proposed a power control technique with a fixed step size [9]. This fixed step, however, causes oscillations with high variation around the SIR_{target}. In addition, when the channel changes rapidly, the fixed step size is unable to properly control the power to compensate the changes. The following subsection provides an introduction to some drawbacks of the fixed step size. Some proposed adaptive PC techniques designed for mitigating such drawbacks will be explained in Section 3.2. Then, in Section 3.3, our proposed adaptive power control technique will be introduced.

3.1 Overview of Adaptive Power Control

The aim of a power control procedure is to ensure an adequate SIR for all mobiles in a system by a simple algorithm. Typically, the procedure requires feedback information from the receiver to adjust the transmitting power at the transmitter side. Such information is delivered by mean of feedback information. Amount of information required by the procedure must be as less as possible, because the feedback is bandwidth expensed. An advanced power control which requires detailed information may provide high performance but may require large amount of bandwidth for the feedback. 3GPP specification proposes that only one information bit should be fed back in a time slot.

Transmitted Power Command (TPC) will be fed back and transmitter obeys this command. TPC is a command to increase or decrease transmitting power. The power is controlled by a fixed step size, typically 1 dB [1]. The transmitter will be controlled to increase OR decrease the transmit power, so that the power will always be oscillated even if the received SIR is close to the SIR_{target}. In addition to the oscillation, the fixed PC step size has another drawback. This drawback will occur when the quality of the radio channel degrades significantly and continuously, called "deep fading" channel. The degradation is a usual behaviour of fast fading environment. The fixed step size lacks abilities to track the significant changes, so that the transmitting power is controlled improperly leading to high variance of the transmitting power. Consequently, other mobiles have to increase their transmit power to compensate the power variation. As a result of increasing power, the total interference in the system will be increased. This situation significantly reduces the system capacity as CDMA systems are interference limited. On the other hand, when the quality of the radio channel elapses the deep fading, the mobiles under this channel should decrease their transmit power in order to minimise the total interference. However, in such the rapid change situation, changing the transmit power by fixed step size of 1 dB is not fast enough to lessen 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 the problems.

There were a number of papers studied on the adaptive step size power control techniques [2], [3], [4], [6], and [8]. In [10], an asymmetric power control step size technique, which the increase and decrease step sizes were asymmetric, was proposed. Another method to increase the adoption of power control in order to reduce the oscillating when the received SIR gets closer to the SIR_{target} was proposed in [3]. This method reduces the step size then the different between the received SIR and SIR_{target} is low and increase 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 3GPP specification if it is operated on 1500Hz basis.

3.2 Adaptive Step Size Algorithms

Adaptive step size algorithms are designed with a capability of reducing the oscillations and increase the speed of power control to follow the rapid change of radio channels. Authors in [6] proposed the Adaptive-Step Size Power Control (ASPC) for 3G WCDMA. The idea of the proposed algorithm can be described as: if the same TPC commands are detected, the step size will be increased. On the other hand, if an alternative succession of up and down occurs, indicating that the update step is too large, the step size will then be decreased. There were seven parameters involved in the algorithm presented in [7]. This large number of parameters complicates the optimization for the algorithm.

Another adaptive step size power control in WCDMA was proposed in [3] and [8]. The idea of this technique is to dynamically adapt the step size by a parameter called the dynamic component of Dynamic Step Size (DSS) [3]. This parameter is defined based on the received SIR and SIR_{target} in a corresponding radio connection. There are two possibilities to implement the proposed method:

- The SIR related information is sent to the transmitter by a dedicated or common channel. The transmitter (i.e. mobile in the uplink) calculates the value of the parameter according to the History Data Analyser Logic (HDAL).

- The dynamic component of DSS is transmitted from base station. Up to three bits of information feedback are required.

The DSS technique proposed in [3] showed a distinguishable performance when compared with the typical 3GPP fixed step size power control algorithm. However, it adds a complexity to the mobile to calculate the dynamic component of DSS. Moreover, it required a large bandwidth for information feedback when operated on 1500Hz.

3.3 Proposed Adaptive Step Size

A new adaptive step size power control technique is presented in this paper. The proposed technique requires the same information as in 3GPP specification, i.e. one bit per 0.667 msec. In addition to the maximum and minimum values of the step size which are common parameters for all adaptive power control techniques, there is only one additional parameter, called Adaptive Control Factor (ACF), involved in this technique.

The power control step size is adapted by multiplying a factor called Adaptive Factor (AF) with the fixed step size (δ in Equation 1). This factor will be updated according to received TPC commands. The block diagram of the purposed power control technique is shown below:

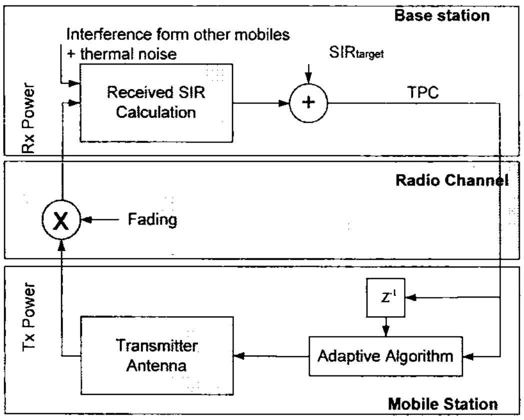

Figure 1 Proposed Adaptive Power Control Model

The proposed algorithm uses two most recent TPC commands to compute the AF based on a predefined AFC. The transmit power is updated according to the following equation:

$$P_u(t+1) = P_u(t) + AF_u(t) \cdot \delta \cdot TPC_u(t) \quad (2)$$

where $AF_u(t)$ is the Adaptive Factor of u^{th} user at time t, and $TPC_u(t)$ is the TPC command of u^{th} user at time t, corresponding to $sign(SIR_{target}-SIR_{est})$ in Equation 1.

The AF will be updated by the following equation:

$$AF_u(t) = \min(\max(\frac{ACF + DF_u(t)}{ACF}, Size_{\min}), Size_{\max}) \quad (3)$$

when $Size_{min}$ and $Size_{max}$ is the minimum and maximum step size respectively. The $DF_u(t)$ is the Dynamic Factor of u^{th} user at time t.

From Equation 3, we can see that $AF_u(t)$ is linearly updated by $DF_u(t)$, thus only a few additional complexity is required at the mobiles.

The DF is updated based on two most recent TPC commands as the following equation:

$$DF_u(t) = DF_u(t-1) - abs(TPC_u(t) - TPC_u(t-1)) + 1 \quad (4)$$

where $abs(x)$ is the absolute value of x.

The proposed algorithm increases the step size i.e. AF when the mobile detects the same sequence of TPC. The same sequence of TPC commands will be occurred when rapid changes of power are required, such as when the radio condition channel rapidly and continuously.

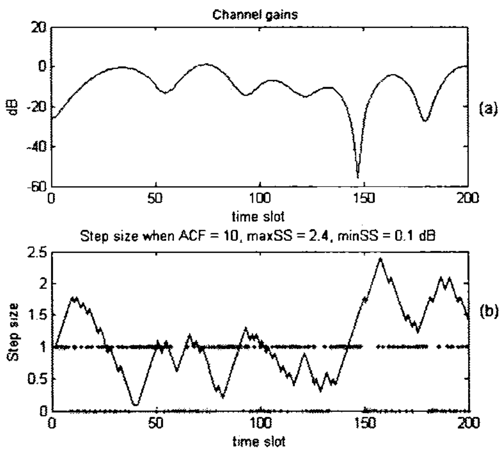

Figure 2 Channel gains, and adaptive step size and TPC commands

Form Figure 2, we can see that when the channel changes slowly (form time slots 10 to 50), the proposed adaptive algorithm decreases the PC step size quickly. Therefore an oscillation of the received SIR will be mitigated (more results on the received SIR will be shown in the section 5). On the other hand, when the channel rapidly changes (i.e. form time slot 130 to 170 in Figure 2), the step size dramatically increases. As a result, the fading can be properly compensated.

4. System Model

The proposed adaptive power control algorithm is evaluated by simulation using MATLAB. The results will be compared to the 3GPP specific power control algorithm, used in UMTS. The details of our simulation and assumptions will be explained in this section.

4.1 Mobile Modelling

Mobiles are uniformly distributed over the simulation area. Each mobile will connect to the closest base station, i.e. 3GPP specification handover is not modelled. The velocity of each mobile will be a constant over the simulation. TPC errors and delays are not considered. The maximum transmit of mobile is 250 mW (24 dBm). The services modelled in this simulation are 12.2 kbps voice services with 100% activity factor. The SIR_{target} for each mobile is 5 dB. The initial transmit power is based on the open-loop power control.

4.2 Base Station Modelling

There are seven cells in the simulation. At the centre of each cell, a base station with an omnidirectional antenna is located. The thermal noise at the base station receiver is -113 dBm. The cell size is 400 m. The system bandwidth is 3.84 Mbps on 1900 MHz carrier frequency.

4.3 Radio Channel Modelling

Three radio link losses are considered in this simulation. They are: the path gain, shadowing, and Multipath fading.

The path gain between mobile i^{th} and base station j^{th} ,$G_{i,j}$,is modelled as:

$$G_{i,j} = \frac{c_{i,j} \cdot m_{i,j}}{d_{i,j}^{4.0}} \quad (5)$$

where di,j is the distance between the mobile i^{th} and base station j^{th} expressed in meter. The coefficient $c_{i,j}$ represents shadowing effects, which is Log-normal random variable with zero mean and 10 dB variance [7]. $m_{i,j}$ is an Rayleigh distribution random variable due to Multipath fading. Flat fading is assumed.

5. Simulation Results

The results form our proposed power control algorithm will be compared to the one of 3GPP in a static environment. The results in the fast fading environment will then be presented in the subsequent section. In order to compare the performance in term of oscillations, Mean Square Error (MSE) of received SIR and SIR_{target} is computed.

5.1 Performance in Static Channel

We first consider the situation when a mobile is the system. In this channel condition, the mobile speed is equal to zero and shadowing effects and Multipath fading effects are not relevant.

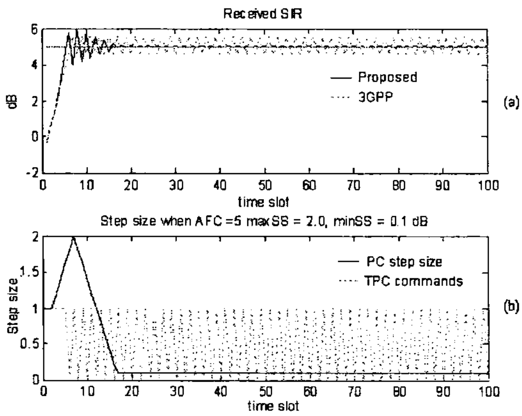

Figure 3 Received SIR both PC schemes, and adaptive PC step size and TPCs in a static channel

From Figure 3 (a), we can see that the novel adaptive scheme outperforms the 3GPP scheme, especially when the received SIR closes to the SIR_{target}. There are only little oscillations around the SIR_{target} by our proposed scheme. This is because the PC step size is decreased accordingly as expressed in Equation 3 and 4 when the different TPC sequences are detected. In this particular simulation scenario, the MSE obtained from the MSE form the 3GPP is 0.37, while the purposed technique is just 0.037.

It must be noted that the result in Figure 3 is a special case when the new scheme significantly outperform the fixed SS scheme. The oscillations of both schemes can be very close in some cases such as when two times of power updates are required during the oscillations resulting in the same two most recent TPC commands. The situation is depicted in Figure 4, (dot line in Figure 4 (b) represents TPC commands and solid line represents the adaptive step size):

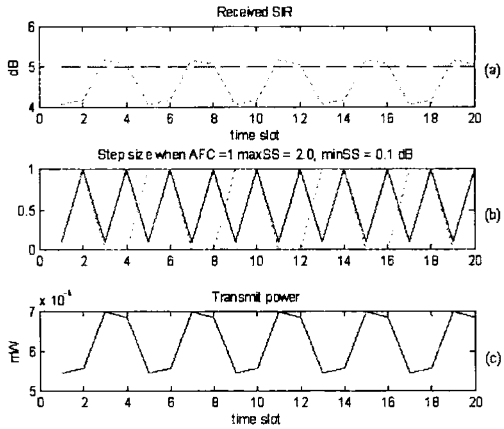

Figure 4 Causes of oscillations

Inspire of such situation, the overall performance of the proposed scheme is still higher than the fixed step. The results from Monte Carlo simulation for 50000 independent mobile positions in a static channel is summarised in Table 1:

	ACF =5	3GPP
MSE	0.2435	0.731

Table 1: MSE in static channels

5.2 Performance in Fast Fading Channel

In this section, the performance of both fixed and adaptive step size power control techniques will be compared in fast fading channels.

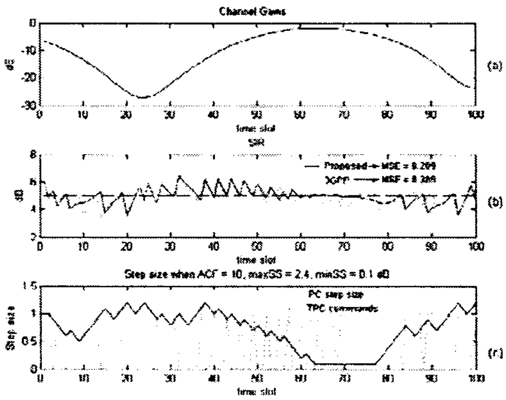

Figure 5 Channel gains, received SIR, and TPC and AF when the channel change slowly

In Figure 5 (b), the received SIR of both the proposed PC algorithm and the 3GPP PC algorithm are plotted. The result shows that when the channel quality changes slowly (i.e. in time slots 60 to 70), the proposed technique reduces the oscillations due to decreased PC step size as shown in Figure 5 (c). The purposed adaptive PC reduces the step size when the channel gain slightly changes. Hence, the new scheme mitigates the oscillations when the received SIR closes to the SIR_{target} in the fast fading channel.

To determine the ability to quickly track the rapid varying in radio channels, we will consider an extreme case when the channel gain dramatically varies. The result is shown in Figure 6:

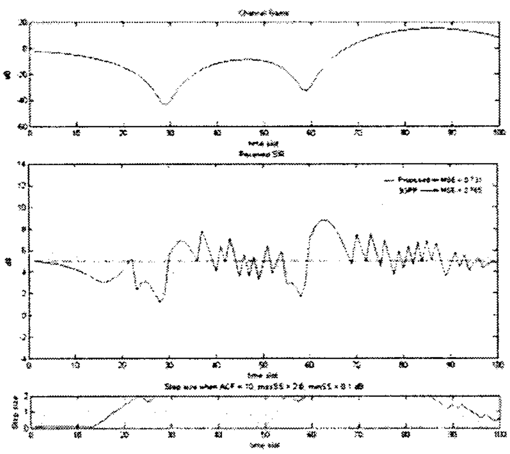

Figure 6 Channel gains, received SIR, and TPC and AF when the channel changes rapidly

In Figure 6 (b), there is a distinguishable difference between the received SIR from the proposed scheme and the one of 3GPP, especially when the deep fades are taken place. This significant result is due to the ability to increase the PC step size when the channel varies continuously as depicted in Figure 6 (c) at which the AF reaches the maximum at most times. In addition, we can see a large difference between MSE of the proposed scheme and the 3GPP scheme i.e. 2.765 for 3GPP algorithm and 0.731 for our proposed algorithm.

The result from Monte Carlo simulation for 10x50000 independent mobile positions in 50000 different channels is summarised in Table 2:

	ACF =5	3GPP
MSE	0.576	0.853

Table 2 MSE in fast fading channels

ACF is an influential factor for the new power control algorithm. The MSE of 10 mobiles is shown in Figure 7.

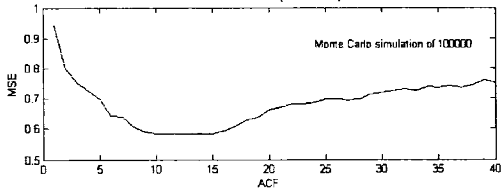

Figure 7 MSE versus AFC in fast fading channels

From Figure 7, we can see that, in fast fading environment, when the value of AFC is low, the MSE decrease as ACF increase, this is because the too low ACF leads to too fast adaptation, resulting in instabilities of the received SIR. On the other hand, when ACF becomes larger i.e. than 20, the MSE starts to increase. This is due to large ACF destroys the adaptability of the algorithm.

6. Conclusion and future works

A new adaptive power control algorithm for UMTS has been proposed in this paper. This algorithm requires only one bit as in 3GPP specification. It shows an outstanding performance over the fixed step size power control in static channels by mean of less oscillations and MSE. Moreover, the purposed algorithm overcomes the fixed step size algorithm in fast fading channels. It is capable for tracking the rapid changes of the fading channels.

7. Reference

[1] H, Holma, and A. Toksala, *WCDMA for UMTS*, fourth edition, Wiley and Sons, 2004

[2] J. Nasreddine, L. Nuaymi, and X. Lagrange, "Adaptive Power Control Algorithm for 3G Cellular CDMA networks" , *IEEE VTC*, vol. 2, May 2004, pp. 984–988.

[3] S. N. Siamak, R. Baghaie, and M. Rintamaki, "Dynamic Step-Size Power Control in UMTS," , *IEEE PIMRC*, 2002.

[4] D.M. Novakovic, and M.L Dukic, "Evolution of the Power Control Techniques for DS-CDMA Toward 3G Wireless Communication Systems", *IEEE Surveys*, Fourth quarter 2000.

[5] M. P. J. Baker, T. J. Moulsley, "Power control in UMTS release'99", *First International Conference on 3G Mobile Communication Technologies*, Mar 2000.

[6] L. Nuaymi, P. Godlewski, and X. Lagrange, "A Power Control Algorithm for 3G WCDMA Systems", *European Wireless*, Florence, Italy, 2002.

[7] "Universal Mobile Telecommunication System (UMTS); selection procedure for the choice of radio tramssion technologies of the UMTS," TR 101 112 (UMTS 30.03), April 1998

[8] M. Rintamki, "Adaptive Power Control in CDMA Cellular Communication Systems", PhD Thesis, Helsinki University of Technology, Department of Electrical and Communication Engineering, Nov 2005

[9] "Physical Layer Procudure (FDD)," Third Generation Partnership Project, Technical Specification Group Radio Access Network, TS25.214 (Release 5), Sep 2003.

[10] J. Kujenniemi, O. Lehitinen, and T. Ristaniemi, "Signaled Step Size of Downlink Power Control of Dedicated Channels in UTRA TDD," 4th International workshop on Mobile and Wireless Communication Network, pp. 675-679, 2002.