Proceedings of the Fourth IASTED Asian Conference
COMMUNICATION SYSTEMS AND NETWORKS
April 2–4, 2007, Phuket, Thailand
ISBN CD: 978-0-88986-658-4

AN ADAPTIVE STEP SIZE POWER CONTROL WITH TRANSMIT POWER CONTROL COMMAND AIDED MOBILITY ESTIMATION

Rachod Patachaianand, Kumbesan Sandrasegaran

Institute of Information and Communication Technologies and Faculty of Engineering
University of Technology Sydney
Email: rpatacha@eng.uts.edu.au, kumbes@eng.uts.edu.au

ABSTRACT
Power control is one of the most important mechanisms influencing on the maximum capacity and performance of Wideband Code Division Multiple Access (WCDMA) systems. Power control algorithms used in Universal Mobile Telecommunication System (UMTS) are based on fixed step size algorithms. The algorithms adjust their transmitted power based on Transmit Power Control (TPC) commands. In this paper, we show that there is a significant correlation between TPC sequences and user mobility. We then introduce a new parameter called Consecutive TPC Ratio (CTR), which will be varied by user speeds. A new adaptive power control algorithm is also proposed. This new power control algorithm uses CTRs to adjust power control step sizes. The result shows that the proposed algorithm outperforms fixed step power control.

KEY WORDS
Power control, WCDMA, UMTS, Mobility estimation, TPC

1. Introduction

Power Control (PC) is one of the most essential radio resource management functions of WCDMA systems where all terminals (also called User Equipment or UE in UMTS) simultaneously share the same radio resource. The maximum capacity of the WCDMA systems relies significantly on interference levels caused by multiple users transmitting on the same channel and at the same time. The received signal powers at base stations (also called “Node B” in UMTS) are considered as the system’s interference. A user close to a base station transmitting excessive power may block the entire system capacity. This phenomenal is called a “near-far” effect. Capacity of WCDMA systems can be maximized by a proper power control algorithm as the algorithm can eliminate the “near-far” effect.

In addition to the task to mitigate the near far effect, power control is responsible for compensating fading due to variations of radio channel such as multipath fading and shadowing effects. Multipath fading causes rapid changes of radio channels while shadowing affects on much slower time scales. Therefore, most power control algorithms are designed to cope with the rapid changes of multipath fading.

Another objective of power control is to keep the power consumption of each mobile at minimal. As a result, the interference is minimized increasing the system’s capacity.

Power control algorithms rely significantly on signal power measurements at the receivers. The receiver employs the measurements such as received Signal to Interference Ratio (SIR) to determine if the transmitter has to increase or decrease the transmitting powers. This procedure is con-ducted based on feedback data sent by the receiver.

In UMTS, according to 3GPP specifications [1] and [2], power control feedbacks are sent by means of Transmit Power Control (TPC) commands. A TPC command contains one power control bit. The commands are fed back 1500 times in one second i.e. on the 1500 Hz basis. The transmitter obeys the command by increasing or decreasing its transmit-ting power by a fixed step, typically 1 dB. This conventional algorithm is capable for tracking the fading with a changing rate, i.e. gradient, of 1.5 dB per millisecond. Although this is seem to be a fast tracking ability, the changing rate of multipath channel is much faster than the tracking ability of the conventional power control particularly when a deep fade occurs. The conversional power control fails to compensate the deep fades because the power control step size is fixed. This limitation leads to a research challenge to design a new fast power control algorithm capable for tracking the rapid change of multipath fading by utilizing existing TPC commands.

This paper is organised as following: standardised power control algorithms are studied in Section 2. The proposed Mobility estimation is proposed and analysed in Section 3. Adaptive Step-Size Power Control (ASPC) is presented in Section 4. Simulation results are given in Section 5. Section 6 concludes this paper.

2. Power Control in UMTS

A. Standardised Inner Loop Power Control

Closed loop power control (CLPC) is available only in dedicated channels in both uplink and downlink [1-3]. CLPC comprises two modes: inner-loop and outer-loop. Inner loop power control is responsible for adjusting the transmitting power to fulfil the minimum SIR target set by outer loop power control. Outer loop power control sets the minimum SIR target for the inner loop power control to maintain the required Quality of Service (QoS) of a connection based on several factors such as Block Error Rate (BLER) and radio channel conditions. Only inner loop power control is considered in this paper.

The inner loop power control algorithm in UMTS updates the transmission power according to the following equation:

$$P_i(t+1) = P_i(t) + \delta_i(t) \cdot TPC_i(t) \qquad (1)$$

where $P_i(t)$ is the transmission power of user i at time t, $\delta_i(t)$ is a power control step size of user i at time t, and $TPC_i(t)$ is a product of received SIR and SIR target determined by

$$TPC_i(t) = sign(SIRT_i(t)\text{-}SIR_i(t)) \qquad (2)$$

where $SIR_i(t)$ and $SIRT_i(t)$ is the SIR target and the received SIR at the receiver for user i at time t, respectively. *sign* is the sign function: $sign(x) = 1$, when $x \geq 0$, and $sign(x) = -1$, when $x < 0$. It can be noted that $TPC_i(t)$=1 is equivalent to TPC bit = 1, and $TPC_i(t)$=-1 is equivalent to TPC bit = 0.

The received SIR of user i at time t in the uplink direction can be computed by:

$$SIR_i(t) = P_i(t) + G_{ij}(t)\text{-}I_i(t) \text{ dB} \qquad (3)$$

or equivalently in a linear scale:

$$sir_i(t) = \frac{g_{ii}(t) \cdot p_i(t)}{\sum_{j \neq i} g_{ij}(t) \cdot p_j(t) + \eta} \qquad (4)$$

where $g_{ii}(t)$ and $G_{ii}(t)$ represent the channel gain between user i and base station j in linear scale and logarithm scale, respectively. η denotes the thermal noise at the receiver, and $I_i(t)$ is the total inference in decibel computed by

$$I_i(t) = 10 \cdot \log_{10}\left(\sum_{j \neq i} g_{ij}(t) \cdot p_j(t) + \eta \right) \qquad (5)$$

3GPP [1] recommends two fixed step size power control algorithms:

Algorithm I

if *the receiver receives TPC command equal to 1*
 Increases the transmission power
else
 Decrease the transmission power
end

This algorithm is capable of tracking rapid fading, but it causes oscillations when the fading is static.

Algorithm II

The receiver will adjust the transmit power by considering a set of TPC commands e.g. 5 commands. The receiver will adjust the power at the end of every set i.e. 5th slot of a set consisting of 5 TPC commands. Transmission powers are constant in slots 1st to 4th and may change only at the 5th slot of a set consisting of 5 TPC commands.

if *the receiver receives a TPC set in which all of 5 commands are equal to 1*
 Increase the transmission power at the 5th slot
elseif *the receiver receives a TPC set in which all of 5 commands are equal to 0*
 Decrease the transmission power at the 5th slot
else
 Maintain the same transmission power
end

When compared with Algorithm I, Algorithm II reduces oscillations but it is not capable of quickly tracking channel variations.

The upper layer of the UMTS Terrestrial Radio Access Network or UTRAN protocol is responsible for switching between these two algorithms. In addition, the upper layers have to monitor user mobility to determine which algorithm should be used.

Another factor which affects on power control performance is the power control step size. Although the 3GPP specification suggests that the typical power control step size is 1 dB, larger step sizes provides lower power control errors (PCE) when the fading rapidly changes i.e. when high Doppler frequency. Figure 1 shows the relations between PCEs as a function of power control step sizes and use speeds (more details about simulation methodology can be found in Section 5):

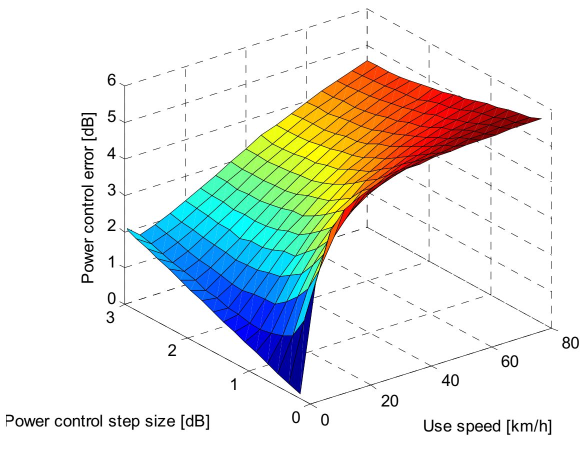

Figure 1 PCEs of different fixed step size PC

From Figure 1, it can be seen that small step sizes at around 1 dB (Algorithm I) can perform efficiently for most of the user speed range (5-80 km/h) although they causes PCEs when user speeds are equal to zero. Algorithm II should be used in cases of no user movements as specified in the 3GPP specifications [1] but it lacks of ability to track changes of multipath fading.

3. TPC commands and Mobility Estimation

3.1 Correlations of TPC commands and Maximum Doppler Frequency

TPC command sequences reflect *implicitly* the changes of radio channels. Consecutive sets of TPC command, e.g. 1 1 1 1 or 0 0 0 0 0, are expected when the channel gains change quickly. There are strong correlations between sequences of TPC command and multipath fading change rates which relate directly to the maximum doppler frequency. The maximum Doppler frequency, f_d, can be computed by:

$$f_d = f_c \cdot \frac{v}{c} \qquad (6)$$

where f_c is the carrier frequency (1.9GHz in this paper). v and c are user speed and light speed (3 x 10^8 m/s), respectively.

From Equation 6, it is obvious that if consecutive sets of TPC commands reflect multipath fading change rates which relate directly to maximum Doppler frequency, then user mobility can be estimated.

The following figure shows the relations between TPC commands and multipath fading gains:

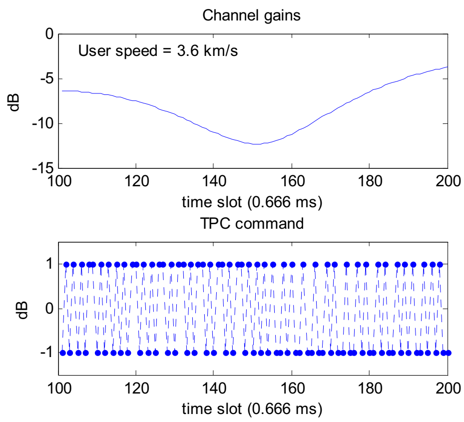

Figure 2 Channel gains with low user speeds

From Figure 2, there are not many consecutive TPC commands because the channel gains change slowly and just a few power adjustments are required. It must be noted that two different adjacent TPC commands result in *no* change of transmission power. Therefore, users with low f_d create only small numbers of consecutive TPC commands which mean not significant power adjustments are required.

On the other hand, if the channel gains rapidly change, many power adjustments will be required. In this case, a large number of consecutive TPC commands will be created as shown in Figure 3:

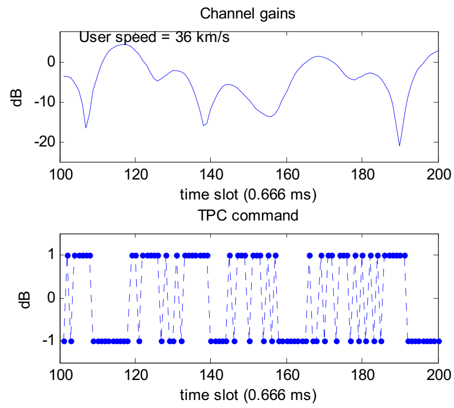

Figure 3 Channel gains with high user speeds

From Figure 3, it can be seen that there are several sets of consecutive TPC commands. The sets of consecutive TPC commands indicate that the transmission powers need to be either increased or decreased in order to compensate the effects of multipath fading.

3.2 Mobility Estimations Using TPC Commands

A new user speed estimation technique utilising only the exiting TPC command information will be presented in this section. We introduce a new parameter called Consecutive TPC Ratio (CTR) as a speed estimation parameter. TCR can be obtained from the following equation:

$$CTR(t) = \sum_{t=t_s+2}^{t_s+t'} \frac{0.5 \cdot |TPC_{t_s} + TPC_{t_s-1}|}{t'} \qquad (7)$$

when t' is the size of averaging window, t_s is an arbitrary beginning time, typically 0. At the beginning, $t = t'$. After that, we may use a concept of widow average which the size of window equal to t_{max}. If t exceeds t_{max}, then t_s will be replaced by $t\text{-}t_{max}$ and t' will be replaced by t_{max}.

Figure 4 depicts the CTR as a function of user speeds and power control step sizes:

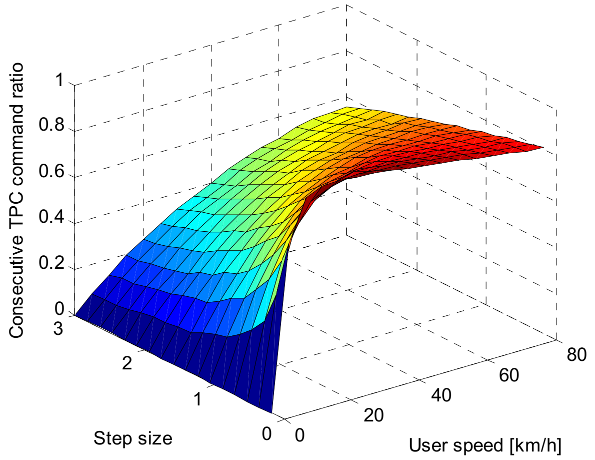

Figure 4 CTR vs PC step sizes and user speeds

From Figure 4, it can be seen that CTRs increase as user speeds increase for all step sizes. In the case of very small step size, CTRs rise dramatically quickly while user speeds increase because inner loop power controls with very small step sizes are not sufficiently fast to compensate the effect of multipath fading. Therefore, continuous up/down commands are released, but the SIR target is not likely to be met. On the other hand, CTRs of power controls with large step sizes increase gradually. It is because those power controls require only a few times of power increasing or decreasing commands to sufficiently track changes in multipath fading channels.

CTRs can also be used as a performance indicator for power control algorithms. From Figure 4 we can see that if the power control step size is very low, which means that the power control algorithm is not sufficiently fast, CTRs become extremely high. It is very high because many consecutive TPC commands to increase or decrease the transmission power will be released, but the SIR target cannot be maintained. On the other hand, fi we consider when the step size is equal to 3dB, CTR is very low. This is because smaller numbers of power up or down commands are sufficient to adjust transmission power to meet the SIR target.

4. Adaptive Power Control Algorithm

The new adaptive power control algorithm adjusts its power control step size based on user mobility. From Figure 1, it can be seen that small step sizes are suitable for very low user speeds while larger power control step sizes are more suitable for high speed users. The new algorithm adjusts the power control step sizes based on user speeds. The power control step size ($\delta(t)$ in Equation 1) will be adapted according to the following equation:

$$\delta(t) = \frac{\alpha}{1-\beta \cdot CTR(t)} \qquad (8)$$

and

$$\delta(t) \in (0, \delta_{max}] \qquad (9)$$

where α and β are constants. δ_{max} is the maximum value of power control step size (4 dB in this paper). α and β must be carefully chosen. From Figure 4 the maximum value of CTR is less than 0.8, therefore β will be computed from:

$$1-\beta \cdot 0.8 \geq 0$$
$$\beta \cdot 0.8 \leq 1$$

Then

$$\beta \leq 1.25 \qquad (10)$$

We chose the maximum value of β because higher the value of β the faster the step size adjustments.

The effects of β on power control step size adjustments are illustrated in Figure 5:

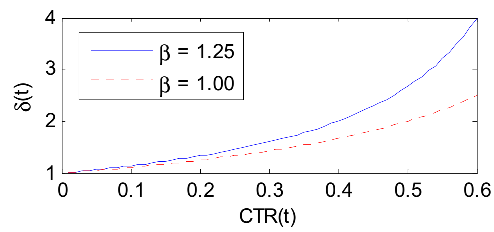

Figure 5 PC step size vs CTR

The effects of different value of α will be presented in the next section.

It is important to note that no addition signalling over the air interface is required for this new algorithm. UE can compute CTR to determine the most suitable power control step size as in Equation 8 by itself.

5. Simulation Results

The performance of the new power control algorithm is simulated using MATLAB. In this paper, an uplink WCDMA system is modelled. No receiver diversity is modelled results in very weak and high variations of signal strengths at the receiver. Simulation parameters are summarised in Table 1.

Parameter	Value in simulation
Propagation Model	$1/d^4$
Thermal noise	-83 dBm
Carrier frequency	1900 MHz
Chip rate	3.84 Mcps
Data rate	12.2 kbps

SIR target	7.0 dB	
RAKE receiver	No	
User speed	0-80 km/h	
Cell size	400 m	
Number of cells	7 cells	
Power control frequency	1500 Hz	
Multipath fading model	**Delay**	**Avg. Power**
	0 s	0 dB
	900 ns	0 dB

Table 1 Simulation parameters

At the end of each simulation, power control errors are calculated to evaluate the performance of power control algorithms. Root mean square (*RMS*) of power control errors is used as the performance indicator of power control.

$$RMS_i = \sqrt{\frac{1}{T} \cdot \sum_{t=1}^{T} (SIRT_i(t) - SIR_i(t))^2} \tag{11}$$

where T is the number of simulation time samples typically 6000 samples in this paper.

The tests are started by investigating the effects of choosing the factor α in Equation 8 under difference mobile speeds. The results are shown in Figure 6:

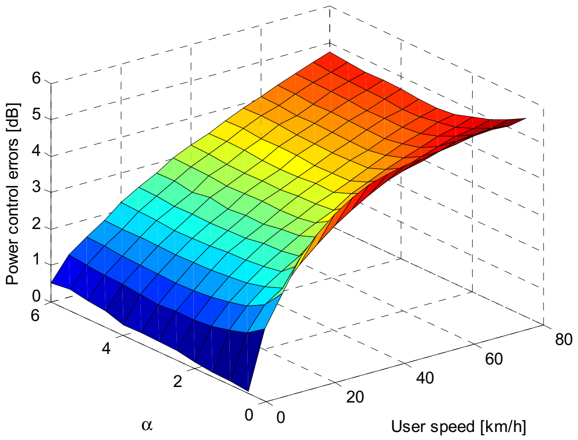

Figure 6 PCE vs α and user speeds

Figure 6 illustrates the power control errors (PCE) as a function of α and user speeds.

From Figure 6 it can be seen that if the value of α is very small PCE rises rapidly when user speeds increase. It must be noted that α is the factor controlling the maximum value of power control step size. If the value of α is very low the maximum power control step size will then be small. Power control algorithms with very small step sizes are not sufficiently fast to track rapid changes of multipath fading. On the other hand, if the value of α is very large, it will cause oscillations in received SIR when user move slowly or do not move. So that, the optimal value of α which provides the lowest PCE is a value between 0 and 6. It can be seen form Figure 6 that the optimal value of α is approximately 3.0. Therefore, the new algorithm with this value will be used to compare with other algorithms.

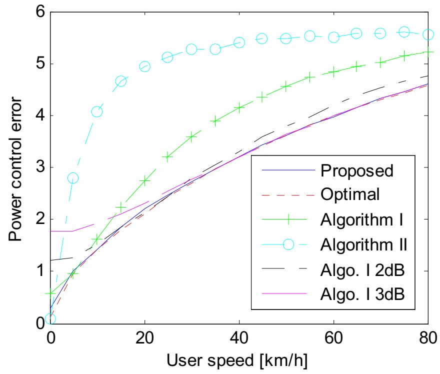

Figure 7PCEs of the proposed algorithm compared to PCEs of other algorithms

In Figure 7, the solid line represents PCE of the proposed algorithm. The dotted line is obtained from the minimum values of Figure 1. There are four reference power control algorithms namely: Algorithm I, Algorithm II, Algorithm I when the step size is equal to 2dB and Algorithm I when the step size is equal to 3dB, respectively.

From Figure 7, it can be seen that the performance of the proposed algorithm is very close to the minimum PCEs obtained from Figure 1. It must be noted that, the minimum PCEs from Figure 1 is proved as the lowest PCE bound of fixed step size power control algorithms only. This means that any fixed step size algorithm cannot provide lower PCEs than this minimum value. The proposed adaptive step size power control algorithm with the aid of the new mobility estimation can provide as the same PCE as the optimal value without additional signalling or advance receiver algorithm.

It is sure that changes in power control algorithm will change CTRs. Fortunately, the resulted CTR shows the similar trend as Figure 2.

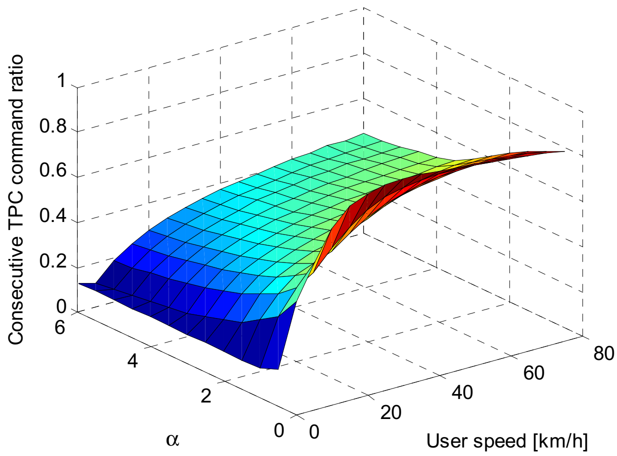

Figure 8 CTR vs α and user speeds

CTRs in Figure 8 are significantly lower than CTRs in Figure 2. As mention in Section 3.2, CTRs reflect the performance of power control algorithms by means of the numbers of up/down commands required for achieving the SIR target. Lower CTRs indicate that lower numbers of power up or power down commands are required to maintain the SIR target.

6. Conclusion

In this paper, a new mobility estimation technique has been proposed. This technique requires only knowledge TPC command which is existing information in UMTS. It has also been shown that there is a significant correlation between user speeds and CTRs. A new adaptive step size power control algorithm utilising CTRs is then proposed. In this new algorithm, CTRs are mapped to power control step sizes based on a particular equation. The result shows that the new algorithm can provide lower PCEs than any fixed step size power control algorithms. In addition to be utilised as a user speed indicator, CTRs can be utilised as a new power control performance indication.

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