MODELING THE IMPACT OF THE FAST POWER CONTROL ON THE WCDMA UPLINK

Kari Sipilä, Jaana Laiho-Steffens, Achim Wacker, Mika Jäsberg

Radio Access Systems
Nokia Telecommunications
PO Box 300, 00045 Nokia Group, Finland
e-mail: kari.sipila@nokia.com

Abstract - The behavior and consequences of the uplink closed loop power control in the uplink of a WCDMA system are analyzed with help of theory and link level simulations. Firstly, the impact of the fast transmit power control (TPC) on the uplink required E_b/I_0 and average transmit power levels are discussed. Furthermore, it is shown how TPC effects can be modeled in network level calculations and an example of TPC corrected capacity numbers is presented. Secondly, the impact of the TPC on the cell range is discussed.

I. INTRODUCTION

In WCDMA radio network dimensioning and planning the link level performance should be modeled as accurately as possible. Various services must be taken into consideration, with different bit-rates, multiplexing and channel coding schemes. In this paper only one of the fundamental issues is discussed, i.e. how to model the effects of the fast power control in uplink.

Accurate power control is one of the basic requirements for the high WCDMA system capacity. The transmit powers must be kept as low as possible in order to minimize interference, and just high enough to ensure the required quality of service. Even though a relatively slow power control algorithm would be able to compensate for large scale attenuation, distance attenuation and shadow fading, the fast power control is needed for multipath fading, in the case of slowly moving mobile stations (MS). This is because for low speed MS:s interleaving does not provide enough diversity.

In Chapter II the impact of the fast power control on the cell capacity is studied. First the statistics of transmit powers is analyzed in the case of ideal power control (PC). Ideal PC keeps the received signal-to-interference ratio constant over time. The deviation of statistics of a real power control from the ideal power control is shown next with help of uplink link level simulations. A method is proposed how the fast power control effects can be taken into account in interference estimation. This is clarified by a numerical example. The fast power control effects on the WCDMA cell range is discussed in Chapter III. Link level simulation results with very limited power control range are presented. Furthermore a suggestion is given for the definition of the fast power control headroom to be used in cell range calculation.

The WCDMA reference system studied here is based on [1] in which there is a fast closed loop power control specified both for uplink and downlink. The system is operating around 2 GHz frequency band with 4.096 Mchip/s chip-rate.

II. THE IMPACT OF FAST POWER CONTROL ON THE CELL CAPACITY

Ideal power control

The instantaneous transmit power of the mobile station (MS) is denoted by p_t. In the ideal power control p_t is set so that the received bit-energy to interference spectral density E_b/I_0 is at constant level just ensuring the desired quality. Here it is assumed that interference is closed to additive white Gaussian noise (AWGN) which is a reasonable assumption in CDMA. ("Interference" is assumed to contain noise and interference throughout the paper.)

The ideal power control equation can be written as

$$G\frac{p_t X}{I} = \rho, \qquad (1)$$

where I is the interference power at the base station (BS), G is the processing gain, ρ is the required bit-energy to noise spectral density ratio and X is the

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instantaneous channel gain varying under multipath conditions. It can be assumed that the expectation value of X is one, $E(X)=1$, since only fast power control effects are studied here. As the power control keeps the signal to interference ratio constant p_t can be solved from (1):

$$p_t = \frac{\rho I}{G}\frac{1}{X} \cdot \tag{2}$$

Thus the statistics of the transmit power is the statistics of the inverse channel gain Y, $Y=1/X$. In the following the expectation value of Y is calculated in some special cases. This is called here the *average transmit power raise* caused by the fast power control.

It is assumed that the signal is received by an ideal RAKE receiver using ideal maximal ratio combining of L multipaths. Then X and its probability density function f_X (pdf) can be written as (see e.g. [2] ,p 802)

$$\begin{gathered} X = X_1 + \cdots + X_L, \qquad E(X_k) = \bar{\gamma}_k, k = 1,\ldots,L \\ f_X(x) = \sum_{k=1}^{L} \frac{\pi_k}{\bar{\gamma}_k} e^{-x/\bar{\gamma}_k}, \qquad \pi_k = \prod_{j=1, j\neq k}^{L} \frac{\bar{\gamma}_k}{\bar{\gamma}_k - \bar{\gamma}_j} \cdot \end{gathered} \tag{3}$$

As an example it can be shown that in the case of L equally strong Rayleigh distributed paths the average transmit power raise is

$$E(Y) = \frac{L}{L-1}, \tag{4}$$

which has been noticed also in [3].

The case of two paths ($L=2$) is analyzed more carefully because it is assumed to be important in reality. Let a be the ratio of the powers of the two paths. Then the pdf of X is

$$f_X(x) = \frac{a+1}{a-1}\left[e^{-x(1+1/a)} - e^{-x(1+a)}\right] \tag{5}$$

and the average transmit power raise is

$$E(Y) = \frac{a+1}{a-1}\ln(a) \cdot \tag{6}$$

If two multipaths and antenna diversity with uncorrelated antennas is considered then the result is effectively four paths and the corresponding pdf and the average transmit power raise are

$$f_X(x) = 4\left(\frac{a+1}{a-1}\right)^2\left[e^{-2(1+a)x}\left(x - \frac{a}{1-a^2}\right) + e^{-2(1+1/a)x}\left(x + \frac{a}{1-a^2}\right)\right] \tag{7}$$

$$E(Y) = 2\left(\frac{a+1}{a-1}\right)^2 - 4\frac{a+a^2}{(a-1)^3}\ln(a) \cdot \tag{8}$$

In Figure 1 the theoretical average transmit power raise from Equations (6) and (8) has been plotted as a function of the average power difference of the two propagation paths.

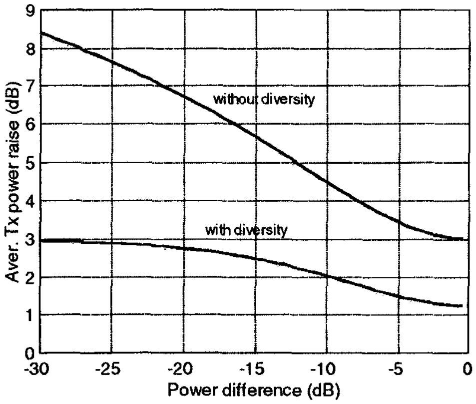

Figure 1. Theoretical average transmit power raise as a function of the power difference between the paths in a two Rayleigh path propagation channel.

Realistic power control

In the uplink closed loop power control of the reference WCDMA system [1] the signal-to-interference ratio (SIR) is measured at the BS and it is compared to a SIR threshold (SIR_{th}). If the measured SIR is below the SIR_{th} an "up" command is sent to the MS, otherwise a "down" command is sent. If the MS receives an "up" command it increases its transmit power by ΔdB, otherwise it decreases its transmit power by ΔdB, within the dynamic range of the MS. The closed power control loop works at 1.6kHz frequency, thus the power control commands are given at 0.625 ms time intervals. (Note: The power control step Δ has been 1dB in the simulations of this study.)

In reality the closed power control is not ideal because of at least the following reasons:

- power is not adjusted continuously
- power adjusting step-size is limited, often constant
- there is a delay between the measurement and adjusting the power according to the measurement
- the estimate of the SIR is inaccurate
- power control commands sent in the feedback channel are misinterpreted
- power control range is finite

The effects of realistic fast closed loop power control was studied with help of simulations. In the simulator the 32 ksymb/s uplink channel of [1] was implemented with a realistic channel and SIR estimation. User data rate was 8 kbit/s and interleaving interval was 10 ms. The propagation channel consisted of two uncorrelated Rayleigh paths with average level difference of 12.5 dB. This is the Pedestrian A channel of [4] converted to the bandwidth of the reference system. Uncorrelated space diversity was assumed meaning 2+2 Rayleigh paths for the RAKE receiver. AWGN noise was added to the signal after propagation channel. In the RAKE receiver model ideal finger allocation was assumed.

The simulations were performed at different mobile speeds without and with fast closed loop power control. Simulation length was 10 000 frames for the pedestrian MS speed (max. doppler frequency 5 Hz) and 3000 frames for other speeds.

In the simulations the received and transmitted power was collected slot by slot. The required received average E_b/I_o was estimated to achieve bit error rate (BER) 10^{-3}. The average power raise was calculated as the average difference between transmitted and received power. The numerical results are given in Table 1.

Table 1. The average E_b/I_o required for BER=10^{-3} with and without fast power control and the average transmit power raise. Channel: Pedestrian A, antenna diversity assumed.

	TPC off	TPC on	
Maximum Doppler frequency	Average received E_b/I_o (dB)	Average received E_b/I_o (dB)	Aver. Tx power raise (dB)
5 Hz	13.1	4.9	2.1
20 Hz	11.5	5.7	2.0
40 Hz	9.7	6.0	1.6
100 Hz	7.9	6.0	0.8
250 Hz	6.5	6.3	0.2

By comparing Table 1 and Figure 1 it can be seen that although there are many sources for non-ideality of power control the average power raise with low MS speed is close to the theoretical model. Also it can be seen that the average transmit power is in every case of these simulations lower with the fast power control than without it directly indicating higher capacity.

To get an idea of the power control efficiency, in Figures 2 and 3 the received and transmitted power distributions has been plotted from the simulations with maximum doppler frequency 5 Hz and 100 Hz respectively. The x-axis has been normalized to the average received power. For comparison the pdf of the propagation channel has been plotted to the Figures 2a and 3a illustrating how well the power control brings the deviation of the received power small. In Figures 2b and 3b the pdf of the inverse channel has been plotted which corresponds to the transmit power distribution in the case of ideal power control. In addition a log-normal fit to the measured average and standard deviation has been included.

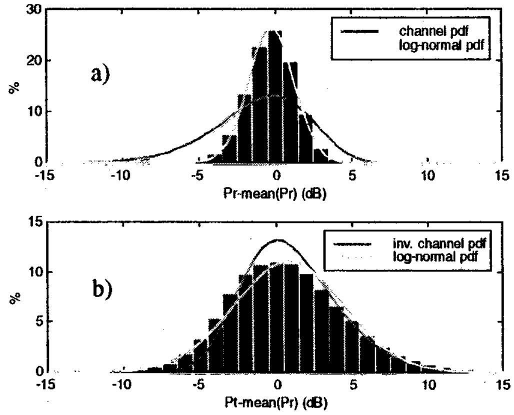

Figure 2. Power control efficiency with maximum doppler frequency of 5 Hz. a) received power b) transmitted power.

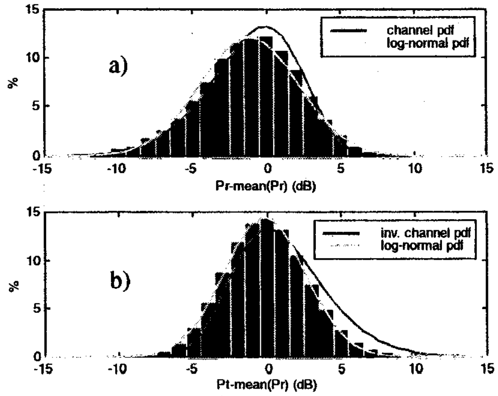

Figure 3. Power control efficiency with maximum doppler frequency of 100 Hz.
a) received power b) transmitted power.

Estimation of average interference and its effect on cell capacity

The average power raise caused by the fast closed loop power control compensating multipath fading should be taken into account in network level calculations when estimating interference and capacity. By following the logic presented in Chapter 6 of [5] one can conclude that the average power raise raises the average interference experienced at a BS. It doesn't raise the average interference from the MS:s connected to this particular cell but it raises the interference from the MS:s connected to surrounding cells likewise in the case of shadow fading when modeled by a log-normal distribution.

Using the same technique as in [5] it can be easily shown that for slowly moving mobiles the other-cell-to-own-cell interference ratio, *f*, should be multiplied with the average power raise to model correctly the effects of fast power control.

The net effect of the reduced received E_b/I_0 and the average power raise due to fast power control can be illustrated by the following example. Suppose that the processing gain is *G*, required E_b/I_0 is ρ, effective voice activity is v, allowed loading (relative to pole capacity) is η_0, other-cell-to-own-cell interference ratio is *f*. Then the number of connections at the nominal loading η_0 can be approximated by

$$M_{\eta_0} = \eta_0 \frac{G}{\rho v(1+f)}. \qquad (9)$$

By giving

$\eta_0 = 0.75$
G = 4.096 × 10^6 / 8000 (8kbit/s speech)
v = 0.67, control channel overhead added to 0.5 voice activity
f = 0.55, in the case of fast power control off
f = 0.55 × (average Tx power raise from Table 1), in the case of fast power control on
ρ = Average received E_b/I_0 from Table 1

one gets the capacity numbers given in Table 2. In reality the capacity is affected by many factors not modeled here, e.g. soft handover. The effect of soft handover on average power raise is studied in [6].

Table 2. Example of estimated cell capacity (Number of connections) with fast power control off and fast power control on.

	TPC off	TPC on
Maximum Doppler frequency	Capacity at 75% load (N. of conn.)	Capacity at 75% load (N. of conn.)
5 Hz	18	98
20 Hz	26	82
40 Hz	40	80
100 Hz	60	87
250 Hz	83	85

III. THE IMPACT OF FAST POWER CONTROL ON THE CELL RANGE

In network dimensioning the average received E_b/I_0 requirement, ρ, is usually the basic number used in calculating the uplink cell range. I.e. it is estimated what is the maximum path loss that can be subtracted from the maximum mobile station transmit power to achieve ρ. With fast power control a *fast fading margin*, or in other words *TPC headroom*, should be taken into account in addition to shadow fading margin to get the correct results for the cell range.

From the single link point of view the fast power control does not increase the cell range. This can be very easily understood by the fact that the furthest point from a BS where a MS can move is when it is transmitting constantly with maximum power. From the capacity point of view this is however not desirable.

Simulation results with limited power control headroom

What happens when a MS approaches cell edge and the transmit power starts to reach the maximum? The quality will get worse and due to this the outer-loop power control should start to raise the target after which the connection will be maintained for a while.

The cell edge effect is studied here briefly with the help of the simulation results made by limiting the power control range above the E_b/I_0 set-point. Only single Rayleigh path propagation channel was simulated with maximum doppler frequency of 20 Hz. The results are presented in Figure 4.

The x-axis of Figure 4. is the target E_b/I_0 towards which the power control tries to target the received E_b/I_0. The y-axis is the required headroom for the power control, so that BER=10^{-3} performance was achieved. Thus moving along the x-axis from left to right emulates approaching the cell edge. It can be seen that by adding just a few decibels to the target $E_b/I_o \approx 4.8$ dB with infinite dynamic range the required headroom comes very clearly down. As soon as the target E_b/I_o is over 7 dB the sum of target E_b/I_o and headroom is approximately constant equal to the required E_b/I_o without power control. In practice this means that the cell edge has been reached and any outer-loop action can't help the situation.

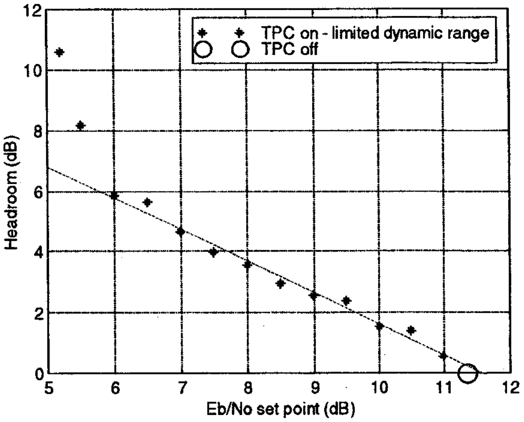

Figure 4. Link level simulation results with limited power control headroom. Propagation channel: One Rayleigh path.

Definition of the TPC headroom

Although the previous example is theoretical because of a special propagation channel it is helpful in understanding what happens near the cell edge and how the TPC headroom should be defined. Based on this it is proposed that for the fast closed loop power control:

TPC headroom =

average required received E_b/I_0 without fast PC —
average required received E_b/I_0 with fast PC

As an example one can take the numbers from the first two columns of Table 1 and estimate TPC headrooms of 8.2, 5.8, 3.7, 1.9 and 0.2 dB corresponding to maximum Doppler frequencies 5, 20, 40, 100 and 250 Hz respectively, for the Pedestrian A channel. These numbers are however only for a single isolated cell because soft handover is not taken into account. The effect of soft handover is studied further in [6].

IV. CONCLUSION

In this paper it has been demonstrated how to model the impact of fast power control on uplink interference, capacity and cell range in a WCDMA system.

When modeling the fast power control in WCDMA radio network dimensioning and planning the counter effect of keeping the received power stable (and low) in multipath fading environment should be taken into account. In interference calculation this can be done by adding an *average transmit power raise* to the interference received at a BS. This is added only to the interference received from the MS:s connected to the surrounding cells. In cell range calculation a *TPC headroom* must be taken into account for the fast power control. This can be defined as the difference between the average required E_b/I_o at BS receiver without and with fast power control.

There are many factors deteriorating the accuracy of the fast power control of WCDMA when compared to ideal power control. Still a clear capacity gain against slow power control is achieved, especially with low speed mobile stations.

The presented methods can be used in analyzing WCDMA network performance and in WCDMA network dimensioning and planning. The analysis here has been performed for the single link case only. Soft handover gains reducing the average received E_b/I_o, the average power raise and the required TPC headroom are analyzed in [6].

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