Performance Analysis of Closed Loop Power Control Methods in the UTRA-FDD Mode

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Abstract - **In this paper, closed loop power control procedures in UTRA-FDD are studied. Fast power control is perhaps the most important aspect in a WCDMA system like this. The research has been carried out through a physical layer simulator that has been implemented in the C language from the standard of the UTRA-FDD mode [1]-[4]. Different parameters have been taken into account: The research has been made in parallel for two mobile speeds, 3 Km/h and 50 Km/h, getting very different results. Different step sizes have been tested. The implementation of an adaptive algorithm to predict the received power to try to improve the power control has been studied, but large improvements have not been obtained. Probability distribution of the power control error and the influence of the distance between the base station and the mobile have also been studied.**

I. INTRODUCTION

Fast power control is perhaps the most important aspect in a WCDMA system like UTRA-FDD [5]-[7]. Without it, a single mobile that reaches a base station with a very high power could block the whole cell. All the mobiles transmit at the same time and at the same frequency. They are separated at the base station thanks to their spreading codes, but these codes are not completely orthogonal, and there is an interference due to the cross-correlation between the codes. The higher the power received is, the higher the interference produced is. This is the well-known near-far problem of CDMA. The capacity of the cell is maximized when all the mobiles reach the base station with the same power.

Open loop power control mechanisms are too inaccurate to obtain this. The reason is that fast fading is uncorrelated between uplink and downlink, due to the large frequency separation of uplink and downlink bands in UTRA-FDD. However, open loop power control is used in UTRA-FDD, but only for the access at the beginning of a connection. Closed loop power control is the solution to this problem. The closed loop power control is also used in the downlink, although in this case the targets are different: there is no near-far problem, but it is suitable to provide additional power to mobile stations at the cell edge, because they suffer from increased other-cell interference.

Simulations about closed loop power control have been carried out to get results about the efficiency of this method.

II. CLOSED LOOP POWER CONTROL

Closed loop power control only exists in dedicated channels [4]. It is divided into inner-loop and outer-loop. Inner-loop has almost the same structure in both links.

The uplink inner-loop power control adjusts the base station transmit power in order to keep the received uplink signal to interference ratio (SIR) at a given SIR target, SIR_{target}. The base station (or stations if the mobile is in soft handover) should estimate signal to interference ratio SIR_{est} of the received uplink DPCH and then generate TPC commands and transmit the commands once per slot according to the following rule:

- If $SIR_{est} > SIR_{target}$, the TPC command to transmit is “0”
- If $SIR_{est} < SIR_{target}$, the TPC command to transmit is “1”

Upon the reception of one or more TPC commands in a slot, the mobile shall derive a single TPC command, TPC_cmd, for each slot. There are two algorithms supported by the mobile for deriving a TPC command. Higher layers determine which of these two algorithms is used.

The step size Δ_{TPC} can take two values, 1dB and 2dB. Higher layers also determine these values.

After deriving of the combined TPC command TPC_cmd using one of the two supported algorithms, the mobile shall adjust the transmit power of the uplink DPCCH with a step of Δ_{DPCCH} (in dB) which is given by:

$$\Delta_{DPCCH} = \Delta_{TPC} \times TPC\_cmd$$

This study is focused on when only one TPC command is received in each slot, that is to say, when the mobile is not in soft handover. In this case, the algorithms are the following:

Algorithm 1

- If the received TPC command is equal to 0, then TPC_cmd for that slot is –1
- If the received TPC command is equal to 1, then TPC_cmd for that slot is 1

Algorithm 2

This algorithm makes it possible to emulate smaller step sizes than nominal step size. The mobile shall process received TPC commands on a 5-slot cycle. The value of TPC_cmd shall be derived as follows:

- For the first 4 slots of a set, TPC_cmd = 0.
- For the fifth slot of a set, the mobile uses hard decisions on each of the 5 received TPC commands as follows:
  - If all 5 hard decisions within a set are 1, then TPC_cmd = 1 in the 5^{th} slot
  - If all 5 hard decisions within a set are 0, then TPC_cmd = -1 in the 5^{th} slot
  - Otherwise, TPC_cmd = 0 in the 5^{th} slot

The downlink inner-loop power control also adjusts the mobile transmit power in order to keep the received downlink signal to interference ratio (SIR) at a given SIR target, SIR_{target}. TPC commands are also generated according to the following rule:

- If $SIR_{est} > SIR_{target}$, the TPC command to transmit is “0”
- If $SIR_{est} < SIR_{target}$, the TPC command to transmit is “1”

In the downlink there are two power control modes:

DPC_MODE = 0

The mobile sends a unique TPC command in each slot and the TPC command generated is transmitted in the first available TPC field in the uplink DPCCH.

The base station shall estimate the transmitted TPC command TPC_{est} to be 0 or 1 and shall update the power every slot.

DPC_MODE = 1

The mobile repeats the same TPC command over 3 slots and the new TPC command is transmitted such that there is a new command at the beginning of the frame.

The base station shall estimate the transmitted TPC command TPC_{est} to be 0 or 1 and shall update the power every three slots.

After estimating the k:th TPC command, the base station shall adjust the current downlink power P(k-1) (dB) to a new power P(k) (dB) according to the following equation:

$$P(k) = P(k-1) + P_{TPC}(k)$$

Where $P_{TPC}(k)$ is the k:th power adjustment (similar to Δ_{DPCCH} in uplink) and is calculated according to the following.

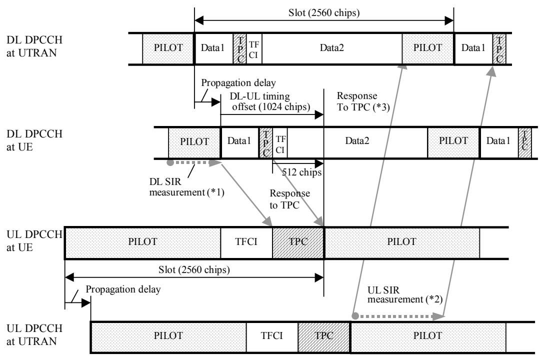
$$P_{TPC}(k) = \begin{cases} +\Delta_{TPC} & \text{if } TPC_{est}(k) = 1 \\ -\Delta_{TPC} & \text{if } TPC_{est}(k) = 0 \end{cases}, \text{(dB)}.$$

The power control step size Δ_{TPC} can take four values: 0.5, 1, 1.5 or 2 dB. It is mandatory for all the base stations to support Δ_{TPC} of 1 dB, while support of other step sizes is optional.

In the downlink, outer-loop power control adjusts the target SIR set up in the base station according to the needs, usually defined as a certain target bit error rate (BER) or block error rate (BLER). In the uplink, there is also another procedure, which is not specified, but open to the manufacturers optimisation. In this study, outer-loop mechanisms have not been included. The target SIR has been a simulation parameter.

Figure 1 shows the transmitter power control timing [4]. The frame timing of an uplink DPCH is delayed 1024 chips from that of the corresponding downlink DPCH measured at the mobile antenna.

Because of this, it can be seen that in the uplink, there is no delay between the slot whose power is estimated and the slot where the power is updated. However, in the downlink there is one-slot delay.



*1,2 The SIR measurement periods illustrated here are examples. Other ways of measurement are allowed to achieve accurate SIR estimation.
*3 If there is not enough time for UTRAN to respond to the TPC, the action can be delayed until the next slot.

Figure 1: Transmitter power control timing

In order to improve the closed loop power control, an adaptive algorithm has been implemented to predict the power that is going to be received in the next slot. The main idea is closed loop power control uses the received power in a slot to update the transmitted power of the next slot. If the received power of that next slot (without updating) could be estimated, the updating could be more accurate. The algorithm that has been used is the Normalized LMS, whose expressions are [9]:

$$\mathbf{w}_{n+1} = \mathbf{w}_n + \beta \frac{\mathbf{x}(n)}{\|\mathbf{x}(n)\|^2} e(n)$$

$$y(n) = \mathbf{w}_n \, \mathbf{x}(n)$$

$$e(n) = d(n) - y(n)$$

Where $\mathbf{x}(n)$ is the input power vector, $\mathbf{w}_n$ is the coefficient vector, $y(n)$ the estimated power, $d(n)$ the real power and β is a normalized step size.

III. SIMULATION

Simulations have been carried out in C, with an UMTS physical layer simulator previously implemented. The simulator consists of a single base station connecting with a single mobile station. The aim of the simulations is to measure the power control error in terms of standard deviation. The main parameters that have been used in the simulations are included in table 1.

A parallel research for two mobile speeds (3 and 50Km/h) has been made. The distance between the mobile and the base station has been fixed at 200 metres and a class 4 mobile has been used. The results that have been obtained at 3Km/h are shown in table 2.

TABLE I.
SIMULATION PARAMETERS

Parameter	Value (for both links)		
Propagation Model	28.6 + 35log10(d) dB, d in metres		
BS Antenna Gain	14 dB		
MS Antenna Gain	0 dB		
Noise+Interference Power	-84 dBm		
Fast Fading Model (*)	Relative Delay [ns]	Average Power [dB]	3 and 50 Km/h
	0	0	
	976	-10	
MS Power Class	Class 4: 21 dBm		
Transmission Rate	240 Kbps (SF_u=16 and SF_d=32)		
SIR_{target}	-8.6 dB		
RAKE receiver	5 branches one-chip delayed		
Transmitted Frames	400		

(*) Case 1 and case 5 of Annex B [8]

In the first case, the error is pretty reduced, especially in the uplink (0.6dB). This error is larger in the downlink than in the uplink, due to the delay of one slot that there is in the power control downlink. If the step size is increased up to 2dB, the error grows. 1dB is enough to keep on channel variations at this speed, and this increase just introduces additional noise.

TABLE II.
RESULTS AT 3 KM/H

3 Km/h	Error standard deviation [dB]	
	Up	Down
Δ_{TPC}=1dB; Algorithm 1; DPC_MODE=0;	0.600	1.046
Δ_{TPC}=2dB; Algorithm 1; DPC_MODE=0;	1.166	2.039
Δ_{TPC}=1dB; Algorithm 2; DPC_MODE=1;	1.207	2.055
Δ_{TPC}=1dB; Algorithm 1; DPC_MODE=0;LMS β=0.2	0.626	1.035
Δ_{TPC}=1dB; Algorithm 1; DPC_MODE=0;LMS β=0.3	1.296	0.919

On the other hand, if the effective step size is reduced with Algorithm 2 and DPC_MODE=1 (although the nominal one is 1dB) the error also grows, so the better solution is the first one. With regard to the use of an adaptive algorithm to predict the received power, there is not a great improvement. With β=0.2, the results are almost equal to not use it and with β=0.3, the control makes worse clearly in the uplink, but there is an improve of 0.13dB in the downlink.

The same simulations have been made with a mobile speed of 50Km/h and the results are included in table 3. A large increase of the error can be seen from this table. Power control can not follow channel variations at this speed. In the uplink, there is an important improvement with Δ_{TPC}=2dB, because higher variations can be followed with higher steps. However, there is no improvement in the downlink, due to the delay in the downlink power control: At 50 Km/h, the channel has a large variation from one slot to the next one, and this makes the power control not be accurate. Logically, if smaller steps were not suitable to keep on channel variations at 3Km/h, they were not suitable at 50Km/h, too. These algorithms are suitable for almost static situations. Finally, the LMS algorithm with β=0.3 provides an improvement between 0.2 and 0.3dB in both links.

TABLE III.
RESULTS AT 50 KM/H

50 Km/h	Error standard deviation [dB]	
	Up	Down
Δ_{TPC}=1dB; Algorithm 1; DPC_MODE=0;	3.520	4.097
Δ_{TPC}=2dB; Algorithm 1; DPC_MODE=0;	2.815	4.535
Δ_{TPC}=1dB; Algorithm 2; DPC_MODE=1;	4.014	5.089
Δ_{TPC}=1dB; Algorithm 1; DPC_MODE=0;LMS β=0.2	3.364	4.291
Δ_{TPC}=1dB; Algorithm 1; DPC_MODE=0;LMS β=0.3	3.262	3.881

In figure 2, an example of the differences between power control at 3Km/h and 50 Km/h is shown.

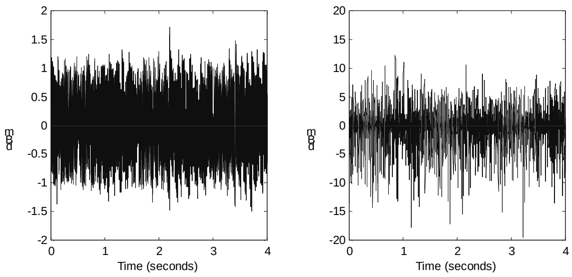


Figure 2 Power control error in the uplink. Δ_{TPC}=1dB; Algorithm 1.
On the left, at 3Km/h and on the right at 50Km/h

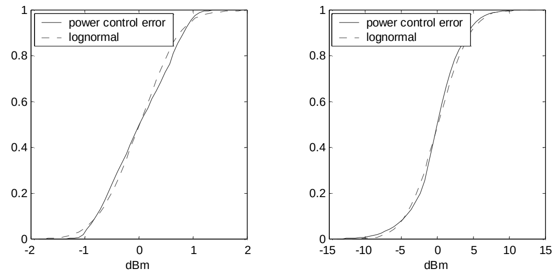


Figure 3 Power control error vs. lognormal probability function. Δ_{TPC}=1dB; Algorithm 1.
On the left, at 3Km/h and on the right at 50Km/h.

Another important aspect has been to demonstrate that closed loop power control error has a lognormal distribution. In figure 3, power control error and lognormal probability function are represented. This allows to introduce the error in simulations of higher layer without including the power control.

Finally, the influence of the distance between the base station and the mobile on the power control has not been taken into account in these simulations. In order to study this influence, that distance has been changed from 200 to 800 metres and two different mobile power classes have been used (Class 4: 21dBm and Class 1: 33dBm). A class 4 mobile can not supply the power to obtain the required power at the base station as it is shown in figure 4.

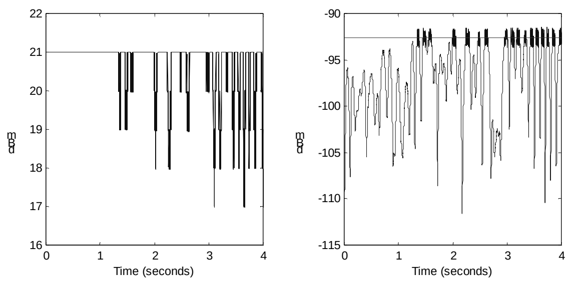


Figure 4 Transmitted and received power in the uplink.
Distance=800m; Power Class 4;
Δ_{TPC}=1dB; Algorithm 1; 3Km/h

However, if a class 1 mobile is used, the power control works correctly, and the received power target is lost just in some specific deep fades, as it can be seen in figure 5.

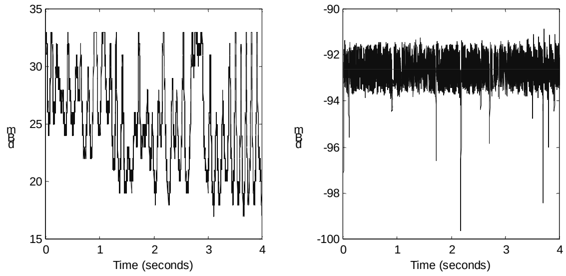


Figure 5 Transmitted and received power in the uplink. Distance=800m; Power Class 1; Δ_{TPC}=1dB; Algorithm 1; 3Km/h

IV. CONCLUSIONS

In this paper, closed loop power control methods in UTRA-FDD have been analysed. These methods work properly at low mobile speeds (pedestrian speeds). However, the error grows when the mobile moves at higher speeds (vehicular speeds), since the power control can not follow channel variations at these speeds. This error increase will reduce the capacity of the cell. In order to calculate this reduction, a study with several mobile stations would be necessary. With regard to the LMS algorithm, a little improvement has been obtained. At low speeds, the error is so low that it can be hardly reduced and at high speeds, because of the low correlation in the channel characteristics for consecutives slots, there can not be a great improvement. Its use does not seem to be a good solution, because the little improvement does not compensate for the complexity of the algorithm and the risk of divergence.

ACKNOWLEDGEMENTS

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