Pathloss-Aided Closed Loop Transmit Power Control for 3G UTRA TDD

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Abstract **– In 3G UTRA TDD, closed loop power control is used as an inner loop power control technique for downlink DPCHs (dedicated physical channels) in the 3.84 Mcps option, and both uplink and downlink DPCHs in the 1.28 Mcps option. In the current closed loop power control, transmit power is generally updated at the frame/sub-frame rate, using a semi-static step size (1,2, or 3 dB). Such a slow transmit power update by a given step size may not be enough to cope with dynamically changing environments, so that the performance of the closed loop power control is degraded. In this paper, we propose an enhanced closed loop power control technique for UTRA TDD, which adapts the step size according to relative pathloss (or power) measurements at the transmitter side. We show that the link-level performance of the proposed power control can be significantly better than the existing closed loop power control. The largest gains are obtained for slow and moderate fading channels.**

I. INTRODUCTION

3G UTRA TDD (Third Generation UMTS Terrestrial Radio Access Time Division Duplex) uses a hybrid time division and code division multiple access scheme. In TDD, multiple user communications are sent over a shared frequency spectrum in both uplink and downlink. As specified in the 3GPP specifications [1], UTRA TDD consists of two options: 3.84 Mcps option and 1.28 Mcps option. For DPCHs (Dedicated Physical Channels) in both options, quality based transmit power control is used as a link adaptation method, such that it adjusts the transmit power of the DPCHs in order to achieve a desired quality of service with minimum transmit power, thus limiting the interference level in the system. The transmit power control can be divided into two processes operating in parallel: inner loop power control and outer loop power control. The inner loop is to keep the received SIR (Signal-to-Interference Ratio) of DPCHs as close as possible to a target SIR value. The outer loop sets the target SIR for the inner loop, based on quality estimates like BLER (Block Error Rate) of the transport channel(s) associated with the DPCHs. In [10], an outer loop algorithm is discussed. Here we focus on the inner loop power control. One scheme to implement the inner loop power control is an SIR-based closed loop power control applied to downlink DPCHs for the 3.84 Mcps option and both uplink and downlink DPCHs for the 1.28 Mcps option. The current TDD closed loop power control typically operates at a frequency of 100 Hz and 200 Hz in the 3.84 Mcps option and 1.28 Mcps option, respectively. When channel conditions are highly dynamic, the closed loop power control with the rather slow power control update rate for the UTRA TDD may not be able to cope with the dynamic channel conditions fast enough. As a result, the performance of the closed loop power control will be degraded. Accordingly it is highly desirable to develop a power control algorithm being capable of fast adapting to channel conditions. In [2], it was shown that the performance of downlink closed loop power control could be improved by signaling the difference between measured SIR and target SIR.

In this paper we present an enhanced closed inner loop power control technique for the UTRA TDD, called "Pathloss-aided closed loop transmit power control''. It exploits the UTRA TDD characteristics: channel reciprocity between uplink and downlink and usage of a training sequence at a fixed transmit power level within specific timeslots like P-CCPCH (Primary-Common Control Physical Channel) [3]. Multi-path propagation conditions are discussed based on the 3GPP standard [7]. In addition, link-level simulations are carried out over the various multi-path fading conditions, in order to evaluate the current closed loop power control and proposed scheme.

II. UTRA TDD INNER LOOP POWER CONTROL

The inner loop power control schemes for DPCHs in UTRA TDD fall into two categories: open loop power control and closed loop power control.

A. Open loop power control

Open loop power control uses the received power measurement of a reference channel which is transmitted on a regular basis with known transmit power. In 3.84 Mcps TDD, uplink dedicated physical channels are dynamically power controlled by open loop control [4]. P-CCPCH (or other beacon channels) is used for the pathloss measurement. In addition to the pathloss estimate, the UE uses power-control related parameters to determine the transmit power required to achieve the target quality. The parameters are signaled by the UTRAN and include the uplink interference, the target SIR from the outer loop, a weighting factor, and a constant value.

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Due to the channel reciprocity between downlink and uplink in UTRA TDD, the open loop control is capable of tracking propagation channel variations. In particular when the delay between the power-controlled transmission and the pathloss measurement is small, the open loop control can quickly compensate for fading channels. The drawback of the open loop control is that it is affected by errors in the absolute power level measurement and power setting [5]. The errors are caused mainly due to the non linear RF amplifier in the transmitter and receiver. However some of the errors can be compensated by using an outer loop power control [6].

B. Closed loop power control

Closed loop power control makes use of feedback information, called "TPC command", signaled from the receiving station of the communication link. The closed loop is employed for downlink dedicated physical channels in 3.84 Mcps TDD and both uplink and downlink dedicated physical channels in 1.28 Mcps TDD. In both TDD options, the receiving station generates TPC commands indicating either "power up" or "power down" according to comparison between SIR measurement of dedicated channels and a target SIR value. At the transmitting station, depending on the received TPC command, the transmit power of dedicated physical channels is adjusted by a pre-defined step size taking the value of 1, 2, 3 dB. For a given closed loop power controlled link, the step size is a CCTrCH (Coded Composite Transport Channel) specific parameter and semi-static.

In UTRA TDD, the closed loop power control is performed on a CCTrCH basis such that the individual TPC command is paired with at least one power controlled CCTrCH. Pairing of TPC command(s) and power controlled CCTrCH(s) is determined by the RNC (Radio Network Controller) and signaled to the UE and NodeB. In general, the closed loop power update rates per CCTrCH in 3.84 Mcps TDD and 1.28 Mcps TDD are 100 Hz and 200 Hz, respectively, which are slow compared to 1500 Hz in UTRA FDD. Furthermore, in the case that either the power controlled link transmission or the TPC command carrying link transmission is paused, the closed loop power control operates at a further slower rate.

Due to the use of a fixed step size and the slow update rate for the closed loop power control in UTRA TDD, a short-term dynamic range of the transmission power step would be limited. Table 1 shows the maximum transmission power step range after receiving 5 TPC commands, which is given by the standard [7]. Here a TPC command group is a set of TPC command values derived from a corresponding sequence of TPC commands of the same duration.

Table 1. Closed loop power control range in UTRA TDD

Step size	Transmitter power control range after 5 equal TPC command groups	
	"Up"	"Down"
1 dB	+4 <= P <= +6	-6 <= P <= -4
2 dB	+8 <= P <= +12	-12 <= P <= -8
3 dB	+12 <= P <= +18	-18 <= P <= -12

III. MODELING OF PROPAGATION CONDITIONS

It is assumed that for the performance analysis of UTRA TDD power control schemes we consider propagation conditions for multi-path fading environments such that the average power level of each propagation channel case is equal to zero in dB. The rationale for this assumption is that the inner loop power control schemes used for UTRA TDD (FDD as well) can fairly well overcome slow fading propagation conditions [8]. In particular we focus here on the multi-path propagation conditions specified in the 3GPP standard [7]. Note that the performance requirements in the standard are specified under multi-path fading conditions. Table 2 shows examples of such propagation conditions. All taps have classical Doppler spectrum. Figure 1 shows channel power patterns for the Case 1 channel and ITU Vehicular A channel (VA 30) with 30km/h, respectively. It is observed that the channel power can considerably fluctuate by 20 – 30 dB, depending on the propagation condition.

In addition, Table 3 presents the statistics of channel power difference in dB between consecutive 10 msec spaced intervals. It should be noted that in 3.84 Mcps TDD the closed loop power control update occurs every 10 msec (per frame) in a normal operation mode. We see that the statistics of the channel power difference are different with different channel conditions. This indicates that the current TDD closed loop power control using a fixed step size can be enhanced by adapting step size according to channel variations.

Table 2. Examples of propagation conditions for multi-path fading environments

Case 1 Speed 3km/h		Case 2 Speed 3 km/h	
Relative Delay [ns]	Relative Mean Power [dB]	Relative Delay [ns]	Relative Mean Power [dB]
0	0	0	0
976	-10	976	0
		12000	0
ITU Pedestrian A Speed 3km/h (PA3)		ITU Vehicular A Speed 30km/h (VA30)	
0	0	0	0
110	-9.7	310	-1.0
190	-19.2	710	-9.0
410	-22.8	1090	-10.0
		1730	-15.0
		2510	-20.0

Table 3. Statistics of channel power difference between consecutive 10 msec spaced intervals

Propagation condition	Mean (dB)	Variance (dB)
Case 1	1.5	1.3
Case 2	0.6	0.3
Case 3	3.2	4.0
VA 30	2.2	2.1

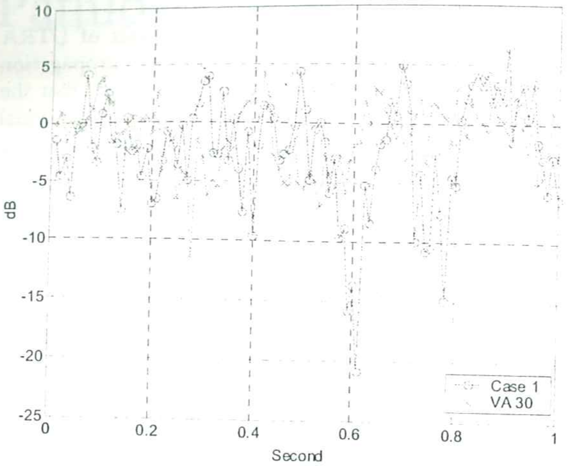

Figure 1. Power in dB of multi-path fading channels

IV. PATHLOSS AIDED CLOSED LOOP POWER CONTROL

In this section, we propose an enhanced closed loop power control scheme for UTRA TDD, which enables the transmitter to autonomously vary the step size in accordance to channel variations. By using the downlink/uplink channel reciprocity in UTRA TDD, relative pathloss measurements are used by the transmitter to estimate the variations. The proposed scheme can be described as follows:

$$P(k) = P(k-1) + \Delta_{TPC}\left(b_{TPC}(k), \Delta PL(k)\right) \qquad (1)$$

where $P(k)$ is the transmit power level in dBm at the k^{th} power update. $\Delta_{\text{TPC}}(b_{TPC}(k), \Delta PL(k))$ represents the power control step size in dB as a joint function of two variables, $b_{TPC}(k)$ and $\Delta PL(k)$, denoting the transmit power control (TPC) command and relative pathloss estimate, respectively, for the k^{th} power update. For simplicity of notation let us use $b_{TPC}(k) = 1$ for "power up" and $b_{TPC}(k) = -1$ for "power down". The relative pathloss estimate, $\Delta PL(k)$, is determined by

$$\begin{aligned}\Delta PL(k) = &\left(\alpha L(k) + (1-\alpha)L_0(k)\right) - \\ &\left(\alpha L(k-1) + (1-\alpha)L_0(k-1)\right)\end{aligned} \qquad (2)$$

where $L(k)$ is the most recent available pathloss estimate in dB before the k^{th} power update. It is assumed that the pathloss measurement is based on a reference channel with known transmit power, for example, P-CCPCH (or other beacon channels) used in UTRA TDD. Here the pathloss measurement is implemented by subtracting in dB the received measured P-CCPCH power from the reference P-CCPCH transmit power. $L_0(k)$ is the long-term average pathloss in dB. $0 \leq \alpha \leq 1$ is a weighting factor, which may be determined according to radio channel condition and the delay, expressed in timeslots, between the reference P-CCPCH timeslot and the power controlled timeslot(s). It should be noted that although absolute pathloss measurement generally suffers from a systematic measurement error, the error can be eliminated when relative pathloss measurements are used.

Figure 2 provides a flowchart of step size determination in the transmitter. This is an example of a possible implementation of Equation (1). As a response to the received TPC command, the transmitter does either increase or decrease its transmit power level, as in the current closed loop power control. However the step size for the power adjustment with the proposed scheme is varied based on the relative pathloss estimate. In case where the channel varies in a direction opposite to the corresponding TPC command such that $b_{TPC}(k) = 1$ and $\Delta PL(k)<0$ or $b_{TPC}(k) = -1$ and $\Delta PL(k)>0$, the transmit power is adjusted by a minimum step size, Δ_{Min}. For the sake of simplicity, integer-valued step sizes are considered here.

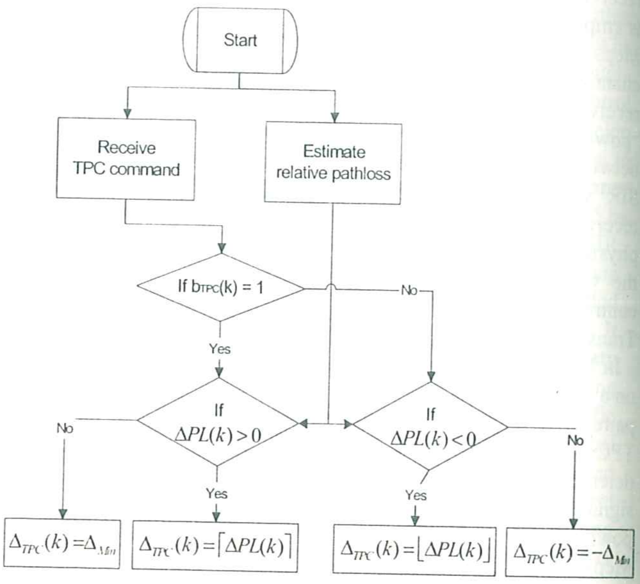

Figure 2. Flowchart of step size determination for the proposed closed loop power control

Since in the proposed scheme the transmitter varies the step size autonomously, the proposed scheme does not require additional feedback signaling bandwidth, as compared with [2]. However a reference physical channel is necessary for changing the step size. Taking into account the current 3G standards, the proposed scheme can be applied to uplink DPCHs for UTRA TDD and TD-SCDMA (Time Division-Synchronous Code Division Multiple Access) [11].

V. PERFORMANCE ANALYSIS

In this section, performance analysis of the current closed loop power control and proposed scheme is provided based on link-level simulations over various propagation channels. Table 4 lists the link-level simulation assumptions. Figure 3 depicts the timeslot configuration considered for the simulations.

Table 4. List of link-level simulation assumptions

Parameter	Assumption/Explanation
Chip rate	3.84 Mcps
Number of Information data bits per transport channel	512 bits
Power update rate	100 Hz (10 msec per update)
Number of codes and timeslots allocated to power controlled channel	7 codes and 1 timeslot per frame
Channel coding	Turbo coding with 4 turbo decoding iterations and Max-log MAP for SISO decoder
Puncturing rate	0 %
Modulation	QPSK
Channel estimation	Ideal
Receiver	MMSE multi-user detector (MUD)
Outer loop TPC	Off
Tx diversity	Off
Propagation condition	Case 1, Case 2, and VA 30
TPC command error rate	5 %

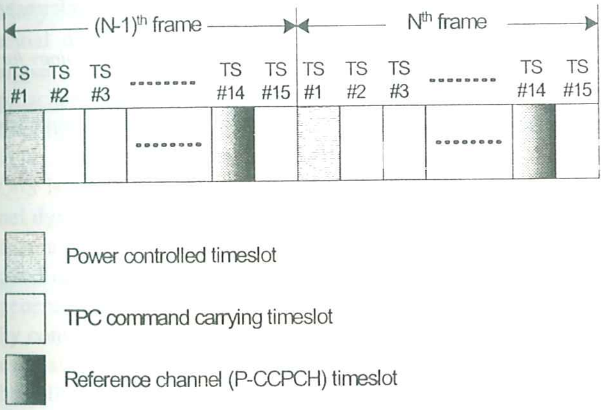

Figure 3. Timeslot configuration for power control simulations

The simulation results are summarized in Figures 5-7. Figures 5-6 are for mobile speed of 3km/h, while Figure 7 is for 30 km/h. Note that UTRA TDD is typically intended for applications in pico and micro cell environments with high density traffic and indoor coverage [9], implying low or moderate mobile speed environments. Figure 5 shows that in the existing closed loop using a fixed step size, the performance with a large step size (2 dB or 3 dB) is better than with the 1 dB step size under Case 1 channel. Under the same channel condition, the proposed pathloss aided closed loop power control provides a significant gain (more than 3 dB at BLER of 0.01) over the current closed loop using an optimal step size for the given channel. The performance advantage of the proposed power control scheme may be illustrated by Figure 4 presenting a sample distribution function of relative pathloss estimate reflecting the channel characterizing Case 1.

From Figure 4 and 5, it appears that as the propagation conditions dynamically vary in time, the proposed scheme is capable of adapting to the channel variations by adaptively changing the step size.

Similarly, Figure 6 shows that the proposed scheme outperforms the current closed loop using any fixed step size in Case 2 channel. Figure 7 presents the performance results over ITU vehicular A channel with a speed of 30 km/h. From the figure, it is observed that the performance of the proposed scheme is better than that of the current scheme. In addition, it can be seen that in the case of the current scheme, the performance with 1 dB step size is better than with 2 and 3 dB step sizes, respectively. Note however that the type of propagation channel is not known at the transmitter, so in addition to adapting to the variations in channel conditions, the proposed scheme adapts to changes in the propagation environment, i.e. whether the conditions reflect Case 1, 2 or 3, or any other propagation model.

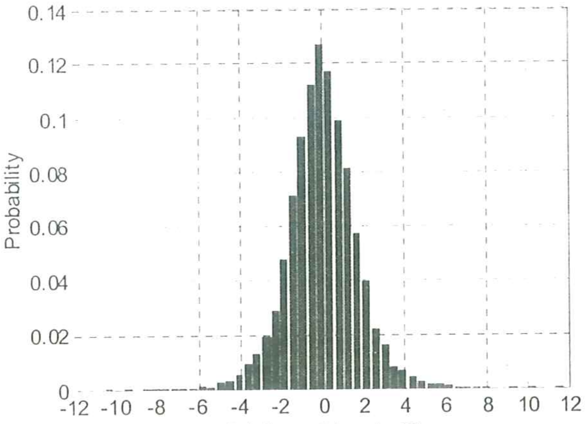

Figure 4. Distribution of relative pathloss in dB in Case 1

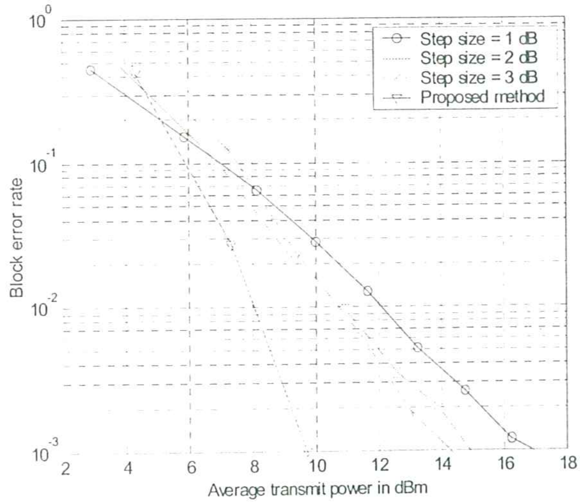

Figure 5. Block error rate vs. Tx power (dBm) for the existing closed loop TPC and proposed closed loop TPC under Case 1

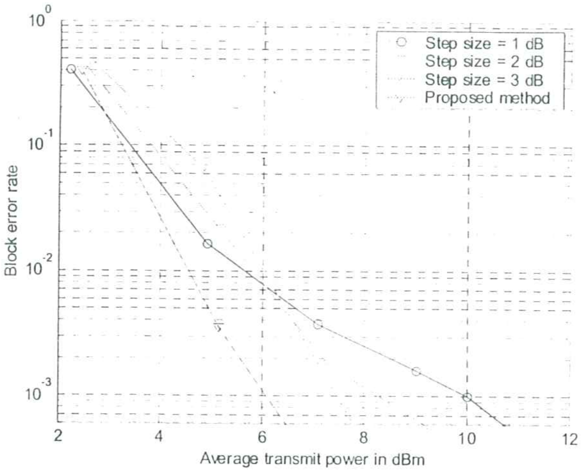

Figure 6. Block error rate vs. Tx power (dBm) for the existing closed loop TPC and proposed closed loop TPC under Case 2

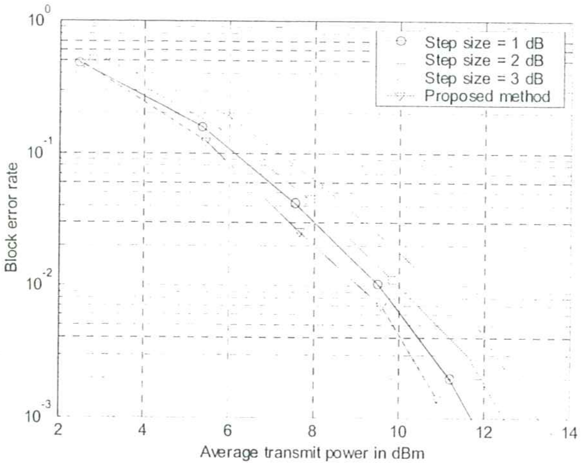

Figure 7. Block error rate vs. Tx power (dBm) for the existing closed loop TPC and proposed closed loop TPC under VA30

VI. CONCLUSIONS

In this paper, we have discussed the closed loop power control in UTRA TDD and proposed an enhanced (pathloss aided) closed loop power control scheme. The proposed scheme utilizes channel reciprocity and relative pathloss measurement to determine the power control step size, so that it can cope with rapid channel changes.

We studied the propagation channels specified in the standard and presented link level simulation results for the proposed power control scheme covering the various propagation channels. The simulation results show that the proposed closed loop power control scheme can offer substantial gains in the required transmit power over the current UTRA TDD closed loop power control scheme These gains lead to significant improvements in TDD system capacity, in particular for slow and moderate fading channels.

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(This paper was accepted but missed in the proceedings of the VTC 2002-Spring, Birmingham, AL, USA)