SIR Estimation Algorithm for Closed-Loop Power Control in W-CDMA System

Khalid A. Qaraqe
Future Mobile Technologies
Research and Development Group
Saudi Telecom Company
kqaraqe@stc.com.sa

Waleed K. Al-Fudhaili
Future Mobile Technologies
Research and Development Group
Saudi Telecom Company
wfudhaili@stc.com.sa

Abstract - An evolution of the UE power control algorithm is proposed for the third-generation WCDMA system. The algorithm is based on coherent SIR estimation scheme and the assumption that frame time synchronization is obtained before demodulating the data with deploying the locally generated pilot symbols for the measured SIR of the Dedicated Physical Channel (DPCH). The proposed algorithm is justified, and a general form of this algorithm is presented. The SIR algorithm is studied in a simple simulation for different propagation channel.

I. Introduction

Power control (PC) is an essential function of CDMA systems. Closed-loop PC is a combination of outer and inner closed loop control. The inner (also called fast) closed loop PC adjusts the transmitted power in order to keep the received Signal-to-Interference Ratio (SIR) equal to a given target. Ensuring that the lowest possible SIR target is used results in greater network capacity.

Inner loop power control is based on SIR measurements at the User Equipment (UE) receiver and correspond a Transmit Power Control (TPC) commands in the Uplink (UL). SIR scheme is very simple to implement and based on PC enables the UE or the Base Transceiver Station (BTS: recently kwon as Node B) to increase or decrease the transmit power. The main reason to enable power control is to reduce the interference level within the cellular network. Reducing power on the BTS or the UE while keeping a reasonable signal quality decreases the interference caused by other cells in the surrounding area which reflects increase in the network capacity. The SIR estimator calculates the SIR on the received DPCH for the downlink power control, then the mobile requests the base station to increase or decrease the downlink (DL) power when the SIR estimate exceeds or drops below SIR target threshold [1,2,3].

DS-CDMA links are interference limited, fast TPC based on the measurement of SIR minimizes the transmit power for a given traffic load and thus minimizes the interference to other users thereby increasing the link capacity. Operators need to test the UMTS handset transmitter and receiver characteristic and UE performance which impact the network capacity.

This target threshold is controlled by outer loop which decreases or increases based on the link quality. In the simulations, the target value assumed equal to the transmitted E_b/N_o. Signal power is estimated for the coherent pilot symbol averaged on the current slot as shown in Figure 1. Interference power on the current slot is calculated by taking the variance of the incoming pilot symbols from the local average. In a fading scenario and in order to remove the fading component from the interference power estimate, the estimated value is averaged over multiple slots using a single pole IIR (α) filter. The value of α should be small enough to average over multiple fade periods for slow fading and large enough to account for varying interference conditions in multipath channel.

In this paper we present and analyze the UE SIR algorithm performance deploying ideal and CPICH channel estimation for different cases of the 3GPP propagation channel [1, 4, 5].

Figure 1 shows the frame structure of the downlink DPCH each frame of length 10 ms is split into 15 slots, each of length T_{slot} = 2560 chips, corresponding to one power-control period. Pilot pattern and power control step size is presented in [2,4] the frame structure for time-multiplexed pilot symbols supports the SIR measurement can be found in [1].

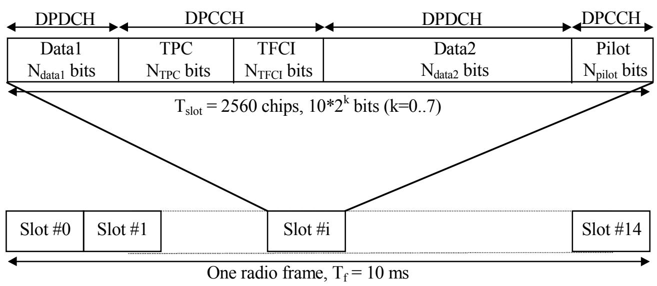

Figure 1: Frame structure for downlink DPCH

II. SIR Estimation

A. Interference Averaging

Due to a limited number of pilot symbols available over a slot, the interference estimate calculated on the current slot, I_{slot}, is subjected to fading. In order to nullify the effect of fading on I_{slot}, we have to average it over multiple slots. Averaging I_{slot} over multiple slots could be performed as: sliding window FIR with 'Window size' as a parameter or by single pole IIR with 'α' (set factor). α value should be small enough to average over multiple fade durations.

Simulation shown that a single pole IIR with α = 0.004 (averaged) gives reasonable performance. For small α, power will be very small to begin with. Hence, the SIR estimate will be very high. In order to prevent the TX amplitude from falling, the TX amplitude update starts after $\left(\frac{1}{\alpha}\right)$ that time slots have passed. This duration is sufficient to stabilize the average interference power [7,8].

B. SIR Algorithm

The SIR estimator calculates the signal to interference ratio on the received DPCH for use in downlink power control. When SIR estimate exceeds or drops below the threshold, the mobile requests the base station to increase or decrease the downlink power [2,3]. This target threshold is controlled by outer loop which decreases or increases based on the link quality such as BLER. In the simulations, the target value is fixed and the value is same as the transmitted E_b/N_o. Signal power is estimated through coherent pilot symbol averaged on the current slot as shown in Figure 2. Interference power on the current slot is calculated by taking the variance of the incoming pilot symbols from the local average. In a fading scenario, this estimate will be subjected to fading as well. In order to remove the fading component from the interference power estimate, this value is averaged over multiple slots using a single pole IIR (α) filter. The value of α should be small enough to average over multiple fade periods for slow fading and large enough to account for varying interference conditions in the multipath channel.

The transmitted signal is represented as

$$x(t) = (d_i + jd_q)c_{ovsf}(sc_i + jsc_q) \qquad (1)$$

Where,
$d_I + jd_j$ is the QPSK data symbol.
c_{ovsf} is the channelization code.
$sc_I + jsc_q$ is complex scrambling code.

After passing through the multipath channel, the signal can be written as $r(t) = x(t)\sum_{i=0}^{L-1} h_i(t) + N(t)$ (2)

Where,
$h_i(t)$ is the complex channel coefficient for *i-th* multipath.
N(t) is complexe AWGN noise.

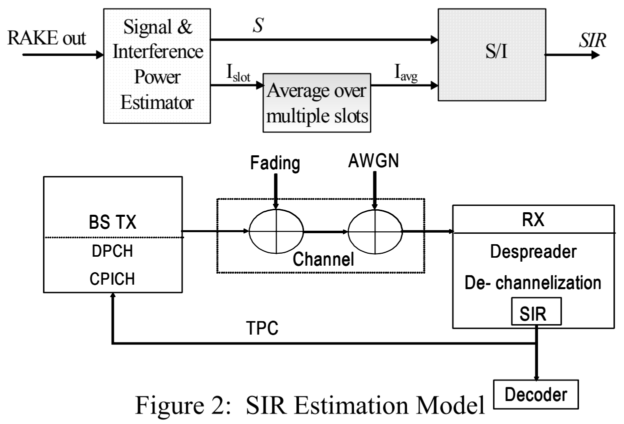

Figure 2: SIR Estimation Model

Hence, signal power at the receiver can be written as :

$$S(t) = \sum_{i=0}^{L-1} h_i^2(t) \qquad (3)$$

Received symbol at time t = nT_s after rake combining can be written as,

$$r(nT_s) = r_i(nT_s) + jr_j(nT_s) \qquad (4)$$

Ignoring the symbol T_s, we will have,

$$r(n) = r_i(n) + jr_j(n) \qquad (5)$$

The standard Deviation of estimated E_b/N_o in dB given by

$$\sigma = \sqrt{\mathrm{var}(10\log_{10}(E_b/N_{oi}))}\ \text{dB} \qquad (6)$$

The mean value of the Estimated E_b/N_o in dB is:

$$\mu = E[10\log_{10}(E_b/N_{oi})]\,\text{dB} \qquad (7)$$

Denoting the pilot symbol during the n[th] symbol duration as

$$p(n) = p_i(n) + jp_q(n) \qquad (8)$$

Signal power on the current slot, S, calculated as :

Top

$$S=\frac{1}{2N_p^{\,2}}\left[\mathrm{Re}\left[\sum_{n=0}^{N_p-1}X(n)p^*(n)\right]\right]^2 \qquad (9)$$

The average value of the pilot symbol amplitude is given by S_{av}

$$S_a=\sqrt{\frac{S}{2}} \qquad (10)$$

where: X(n) is the complex received symbol at the RAKE output, S is the signal power, S_a is the average received signal amplitude, N_p is the number of pilot symbols.

Then, interference measured over a slot can be written as, I_{slot} is

$$I_{slot}=\frac{1}{N_p}\sum_{n=0}^{N_p-1}(X_i(n)-S_a*p_i(n))^2+(X_q(n)-S_a*p_q(n))^2 \qquad (11)$$

The interference power, I_{slot}, is passed through a low pass filter or is averaged using a sliding window filter. In the case of ß filter the averaged interference power can be written as:

$$I_{avg}(n)=(1-\alpha)I_{avg}(n-1)+\alpha\, I_{slot}(n) \qquad (12)$$

SIR is then the ratio of signal to interference power

$$SIR=\frac{\text{Signal Power}}{\text{Avg. Interference Power}}=\frac{S}{I_{avg}} \qquad (13)$$

The RAKE output used for the purpose of SIR estimation should not be delayed due to channel estimation. Consequently, the despreaded symbols are subject to errors introduced due to imperfect channel estimation. This effect becomes severe at high Doppler frequencies and low E_b/N_o conditions, ideal and CPICH channel estimation were used for SIR simulation [9].

C. Test Environment

Test environment and simulation parameters are described in table 1

Table 1 Simulation Parameters

Parameter name	Default Value	Description
Number of TPC bits	2,4,8	Depends upon the physical channel rate
Number of Pilot symbols per slot	2, 4, 8,16	Depends upon the physical channel rate
Total number of symbols per slot	20	Depends on the physical channel rate
Number of symbols used to calculate the avg.	4	Set to the same number of the of pilot symbols in a slot.
signal power		
Reference value of E_b/I_0 (linear)	1	Exported from the E_b/N_o at the system level
Power increment	1 dB	Step change in the power level at the transmitter of Node B.
Interference averaged using	'Single pole IIR'	'Single pole IIR' or 'sliding window FIR'
Sliding window length(slots)	250	Number of slots used for averaging when Sliding Window FIR filter is used.
Forgetting factor (α)	0.004	Forgetting factor of the Single Pole IIR filter.[7,8]
Sampling rate	1 sample/ chip	
Propagation Conditions	AWGN and Raleigh Fading	Channel model described in 3GPP/UMTS standardization [3] case 2, case 3 and case 4]
Channel estimation	Ideal, IMALI, & CPICH	[9]
TPC_cmd	1 , 0	
Power control Cycle	1/1500 sec	

III. Simulation Results and Discussions

The performance of the closed-loop power control of WCDMA-FDD system is evaluated in [6], for the two algorithms proposed in [3]. The evaluation is done for different values of the SIR estimation standard deviation error.

The bias on the SIR estimates changes with different Dopplers if the interference averaging is not performed over enough slots. In other words, ß should be a small number. We pick the ß value to be 0.004 because it is an optimum value that roughly corresponds to averaging 250 slots. Figure 3 shows that the typical value of α is 0.004 for space time transmit diversity (STTD) and for no diversity (ND) case, more details of the STTD mode is illustrated in [3,4,7].

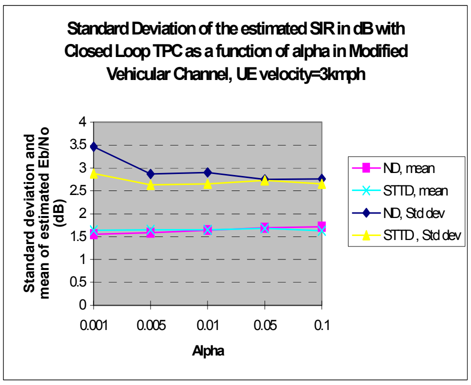

Figure 3: Simulation results: closed loop TPC: standard deviation/mean versus α.

The SIR Algorithm is evaluated in simulation for single Rayleigh and multi-path fading at different UE speedbetween zero and 120 km/h. The simulated service is 8 kbps circuit switched service, interleaving depth is 20ms. The outage BER probability is plotted as a function of the SIR target. Figure 4, 5 and Figure 6 shows the required E_b/N_o for different services that needs a BER of 10^{-2} and 10^{-4} , as illustrated in the simulation results we can see that UE SIR E_b/N_o target depending on the Doppler frequency.

The net effect on the coded BER for ND and STTD is shown in Figure 6. We can see that the optimal performance is achieved at UE speed of 60 Km/h.

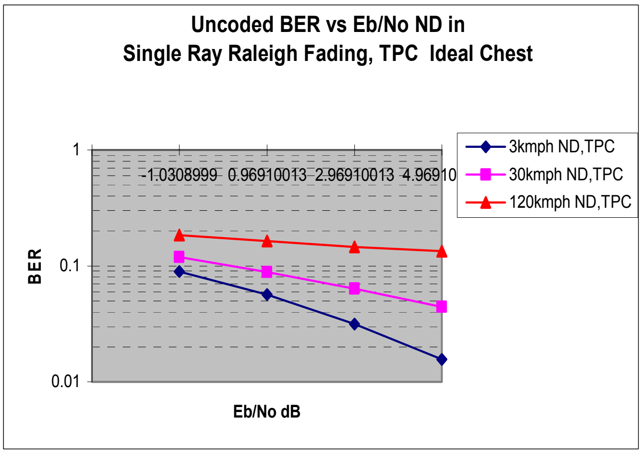

Figure 4: Simulation results: closed loop TPC: single Ray Raleigh fading: E_b/N_o. Vs. uncoded BER.

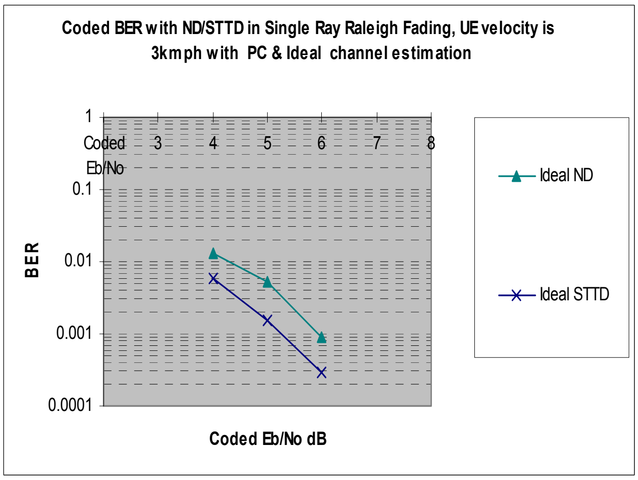

Figure 5: Coded BER for ND and STTD with closed loop TPC, ideal channel estimation for UE velocity of 3km/h.

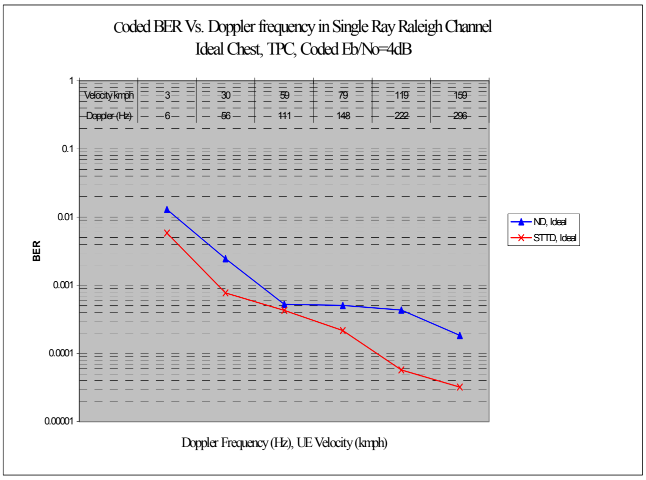

Figure 6: Coded BER Vs. UE velocity, for STTD and ND with ideal channel estimation , TPC at Eb/No = 4dB.

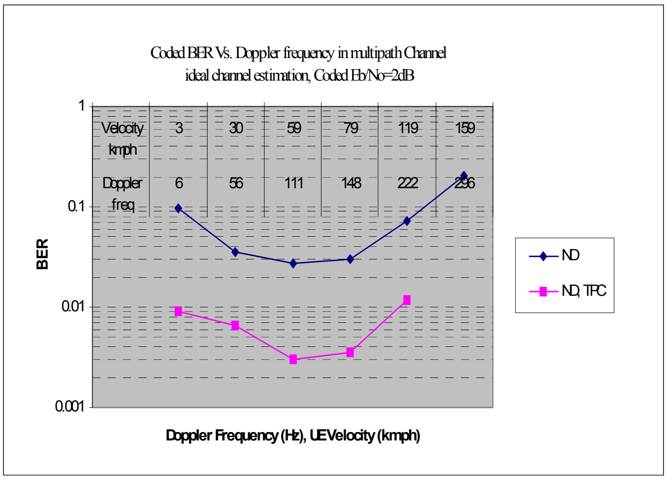

Figure 7: Coded BER Vs. UE velocity in vehicular channel at Eb/No=2dB, ND, and ideal channel estimation.

Figure 7 illustrates that with increase in Doppler frequency, the closed loop TPC performance degrades, we can observe that the BER is the lowest at medium velocities (30kmph to 60kmph) and relatively high at lower and higher velocities. This is due to the fact that at low velocities, the interleaving gain is minimum at high velocities, there is an appreciable degradation due to channel estimation even though the interleaving gain is high. From these curves, we can infer that at high Doppler frequencies, the performance is a direct function of the quality of channel estimates.

The averaged estimated SIR follows the Tx E_b/N_0 very closely in the vehicular channel. However, in Single ray Raleigh fading there is a DC bias introduced in the curve and the bias is a function of Doppler frequency. The standard deviation of the estimated E_b/N_0 decreases with increasing E_b/N_0 until it reaches the saturation.
As the Doppler frequency is increased, the standard deviation increases and saturates the Doppler frequency >

Top

111 Hz. saturation occurs rather slowly in the case of ideal SIR estimation in the Vehicular Channel. Hence, we can infer that closed loop TPC will lose its effect after the saturation point (around 50 to 60 km/h) and it will perform best at lower Doppler as the standard deviation is very low (2 to 3 dB at 3 km/h). Typically, Raleigh fading may fade as deep as 30dB's. As the value of alpha is reduced to 0.001, the standard deviation of the estimated E_b/N_0 increases.

IV. Conclusion

SIR algorithm for DL power control in 3G WCDMA-FDD system is studied in this paper. A new coherent SIR estimation algorithm is developed which uses the locally generated pilot symbols for measuring the signal to interference noise ratio on the dedicated physical channel. This algorithm outperforms other algorithms at low E_b/N_o conditions. A convenient/optimal selection of the parameters according to the mobile network environment such as mobiles speeds characteristics, STTD, propagation channel model are analyzed.

We notice that the coherent SIR power control algorithm, which could be easily implemented, is an interesting variant of the UE speed and outer power control target E_b/N_o, consequently the UE keeps lowering its power even when the actual E_b/N_o received is low, resulting in a higher BER. We show some results of the SIR algorithm for a given numerical parameters set of the algorithm. The quicker convergence of the proposed SIR to the present version of power control in WCDMA may give a capacity increase. The general form of the algorithm allows further studies according to specific mobile network environments.

References

[1] TS 25.211,"Physical Channels and Mapping of Transport Channels onto Physical Channels (FDD)", 3GPP Technical Specification Group Radio Access Network, Jun. 2001.

[2] 3G TS 25.101,"UE radio transmission and reception (FDD)", 3rd Generation Partnership Project; Technical Specification Group Radio Access Network, March 2002.

[3] 3GPP TS 25.213: "Spreading and Modulation (FDD)". 3GPP Technical Specification Group Radio Access Networks, March 2002.

[4] 3G TS 25.214 v4.1.0 (2001-06), "Physical layer procedures (FDD)", 3rd Generation Partnership Project; Technical Specification Group Radio Access Networks, Jun. 2001.

[5] 3GPP TS 25.215: "Physical layer – Measurements (FDD)", 3rd Generation Partnership Project; Technical Specification Group Radio Access Networks, Jun. 2001.

[6] S. Gunaratne, S. Nourizadeh, T. Jeans, R. Tafazolli, "Performance of SIR-Based Power Control for UMTS," in Proc. of *Second International Conference on 3G Mobile Communication Technologies*, Mar. 2001.

[7] F. Adachi, M. Sawahashi and H. Suda, "Wideband DS-CDMA for Next-Generation Mobile Communications Systems", *IEEE Communications Magazine*, September 1998.

[8] John G. Proakis, *Digital Communications, 3rd Edition*, McGraw-Hill Inc.

[9] Khalid A. Qaraqe and Sonia Roe "Channel Estimation Algorithms for Third Generation" *The IEEE Semiannual Vehicular Technology Conference VTC2001",* Rhodes, Greece May 6-9, 2001.

Top