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Source: InterDigital Communications Corporation

Title: Performance Evaluation of Combined Closed-Loop/Open-Loop Power Control Scheme for TDD

1 Introduction

This paper evaluates the performance of power control schemes for power control of uplink dedicated channels in TDD. The paper considers combined power control schemes in which the performance of the closed-loop scheme is enhanced by incorporating open-loop path loss measurements. Such a combined scheme is especially suited for TDD due to channel reciprocity and the availability of two common down link slots per frame. Furthermore, the performance of closed loop power control in TDD is limited due to the slow update rate – when one slot per frame is assigned to a user, the closed loop power control update rate is 100 cycles per second. This update rate is too low in a fast fading channel. Incorporating an open loop component into the power control procedures may enable tracking of fast fades.

Document S1.24 (TDD, Physical Layer Procedures Description) adopts ARIB's proposal for a combined closed-loop/open-loop power control scheme. The current proposal does not allow disabling of the open loop component. More generally, it does not allow assigning a quality-based weight to the open loop component. Furthermore, it may be desirable from network operator point of view to have the ability to turn off open-loop power control or reduce its contribution to the overall power control adjustment. The simulation results in this paper demonstrate that a scheme with an adjustable weight of the open loop component may lead to a significant gain in performance of the power control procedure. This paper presents two new schemes for combined closed-loop/open-loop power control. In both schemes the open loop component is weighted by a parameter $0 \leq \alpha \leq 1$ for demonstrating the basic concept although other values for α can be considered.

Section 2 presents the power control schemes that will be evaluated in this paper; ARIB's scheme, closed –loop power control, and two new schemes proposed by InterDigital: Scheme I and Scheme II.
The relative performance of these schemes is evaluated by simulation. The simulation is described in Section 3. Section 4 summarizes the simulation results. The conclusions are given in Section 5.

2 Combined Power Control Schemes

2.1 ARIB's Scheme

Denote by P_{BTS} the desired received power at the base station and by T_{MS} the transmitted power of the mobile. Let b_{TPC} be the TPC bit (± 1), Δ_{TPC} be the closed loop step size, R_{MS} be the received power of the down link common channel and T_{BTS} be the transmitted power of the down link common channel (broadcasted on the down link common channel). All powers are measured in dB. Note that T_{BTS}-R_{MS} provides an estimate of the pathloss L. ARIB's proposal provides the following formula for describing the combined closed-loop open-loop scheme.

$$T_{MS} = (P_{BTS} + b_{TPC}\Delta_{TPC}) + \hat{L}$$
$$= (P_{BTS} \pm \Delta_{TPC}) + (T_{BTS} - R_{MS})$$

In the simulations, ARIB's formula is implemented as,

$$T_{MS}(n) = P_{BTS}(n) + \hat{L}(n)$$
$$P_{BTS}(n) = P_{BTS}(n-1) + b_{TPC}(n)\Delta_{TPC}$$
$$b_{TPC}(n) = \begin{Bmatrix} 1 & SIR(n-1) < SIR_0 \\ -1 & SIR(n-1) > SIR_0 \end{Bmatrix}$$

SIR_0 is the desired (target) SIR. The simulations of this paper assumes that one uplink slot per frame is assigned to the user. In this case n is the frame index, and L(n) is the most recent available estimate of the path loss.

2.2 Closed Loop Power Control

Closed loop power control can be described by the following equations:

$$T_{MS}(n) = T_0 + G(n)$$
$$G(n) = G(n-1) + b_{TPC}\Delta_{TPC}$$

G(n) is the closed loop gain at frame n. $T_{MS}(n)$, b_{TPC} and Δ_{TPC} are as defined for the ARIB scheme.

2.3 Scheme I

Scheme I is a slightly modified version of ARIB's scheme which allows weighting of the open loop components. It can be described by the following equations:

$$T_{MS}(n) = T_0 + K(n)$$
$$K(n) = G(n) + a\hat{L}(n)$$
$$G(n) = G(n-1) + b_{TPC}\Delta_{TPC}$$

K(n) is the power control gain at frame n, G(n) is the closed loop gain at frame n, and $T_{MS}(n)$, b_{TPC} and Δ_{TPC} are as defined for the ARIB scheme. L(n) is the most recent available path loss estimate. $0 \leq \alpha \leq 1$. When $\alpha = 0$, open loop power control is disabled. When $\alpha = 1$, open loop power control is enabled with maximal weighting. Intermediate values may be used to reflect reliability of open loop estimates. In the following simulations we use the following values of α.

- $\alpha = 1$
- $\alpha = 0.5$
- $\alpha = 1-(D-1)/6$; D is the delay, expressed in number of slots, between the uplink slot and the most recent down-link slot. Note that $\alpha = 1$ for a delay of one slot (minimal delay), and $\alpha = 0$ for a delay of 7 slots (maximal delay).

2.4 Scheme II

Scheme II can be described as follows:

$$T_{MS}(n) = T_0 + K(n)$$
$$K(n) = K(n-1) + b_{TPC}\Delta_{TPC} + a\hat{L}(n)$$

Note that in Scheme I, path loss estimates only provide correction to the instantaneous transmitted gain and do not affect the closed loop gain updates. In scheme II, path loss estimates affect the update of the closed loop gain. In the simulations we will use the same values of α for Scheme II as for Scheme I.

3 Simulation model and Assumptions

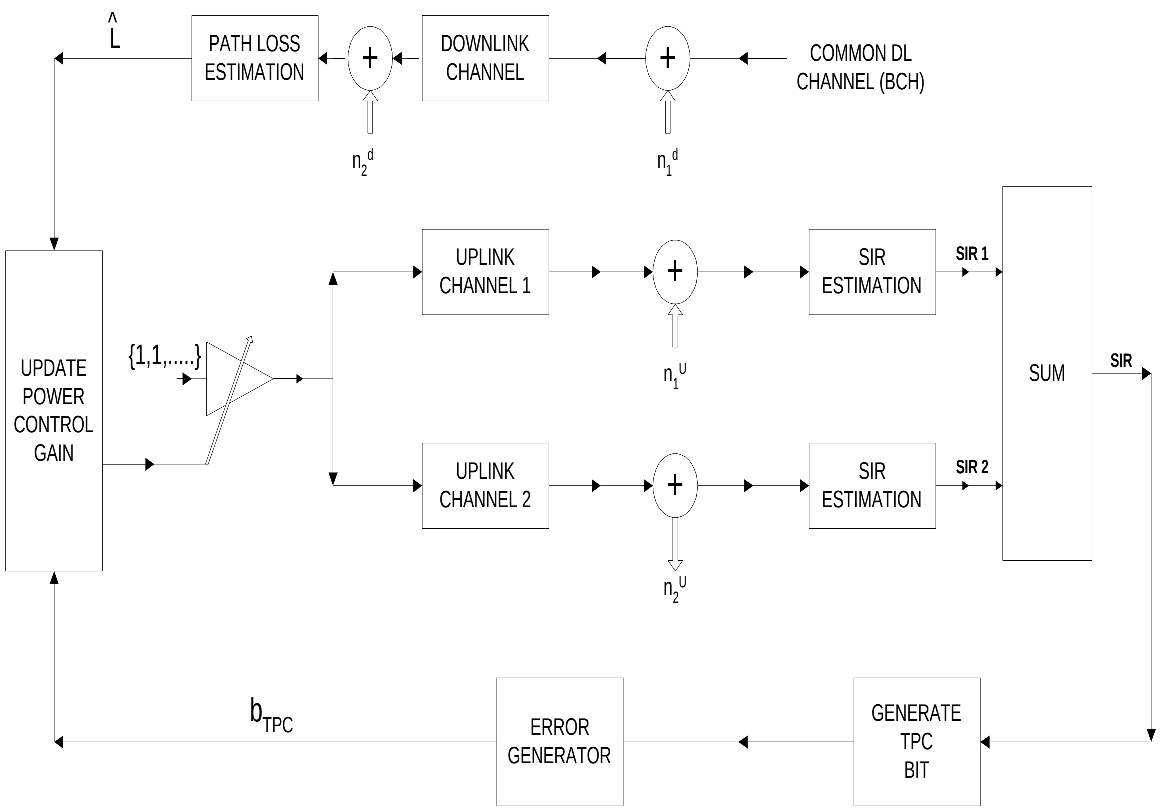

Figure 1: Simulation Block Diagram

A generic block diagram for the simulation is given in Figure 1. The simulation is performed at the symbol rate. It implicitly assumes a spreading factor of 16 for both the downlink common channel and the uplink power controlled channel. The simulation makes the following assumptions:

1. Additive noises n_1^u, n_2^u, n_1^d, n_2^d are independent white Gausssian noises with unity variance. For simplicity n_1^d is ignored in the initial stages of this study. Note that n_1^d represents interference from other users. This is a reasonable simplifying assumption since channelization codes provide orthogonality between downlink channels.
2. The uplink and downlink channels are simulated according to the ITU channel model [ITU-R M.1225, vehicular, type B]. We used the channel coefficients which were created and distributed by Nokia as part of the Turbo-codes effort. The same set of channel coefficients is used for all three channels.
3. The path-loss is estimated at the mobile station following the reception of the downlink BCH channel. The path-loss is therefore estimated at a rate of 200 cycles per second (twice per frame). The path loss estimate is given by the following equation where T_{BTS} is the (known) transmitted power of BCH. We assume RAKE combining for both the mobile and the base station, and receive antenna diversity at the base station. Accordingly, the received power at the mobile station is estimated as the sum of the received signal powers of each of the multipaths. R^k_{MS} denotes the received power of the k-th multipath at the mobile station, and $P(n_2^d)$ denoted the power of the down-link noise n_2^d.

$$\hat{L} = 10\log_{10}\left(\frac{\hat{T}_{BTS}}{\left[\sum_{k=1}^{K}\hat{R}^k_{MS}\right] - P(n_2^d)}\right)$$

4. SIR is estimated at the base station following the reception of the uplink channel. The SIR is estimated by the following equation where SIR_m, m=1,2, is the estimated SIR of the m-th antenna. R^k_m denotes the received power at the k-th multipath of the m-th antenna. $P(n^u_m)$ denotes the power of the noise at the m-th antenna.

$$S\hat{I}R = 10\log_{10}\left(S\hat{I}R_1 + S\hat{I}R_2\right)$$

$$S\hat{I}R_m = \frac{[\sum_{k=1}^{K}\hat{R}^k_m] - P(n^u_m)}{P(n^u_m)}$$

5. The TPC bits are received with an error rate of 10%.

4 Simulation Results

The simulation described in this sections assumes the following parameters:

- Closed loop power control step size: 1 dB.
- Target uplink SNR: 7 dB.
- Mobile speed: 30 km/h.

The simulation results are summarized in Figures 2-7. Figures 2, 4 and 6 show the standard deviation of the received SNR as a function of the delay between the uplink slot and the most recent down-link slot, where the delay is expressed in number of slots. Figures 3, 5 and 7 show the normalized bias of the received SNR as a function of delay. The normalization is performed with respect to the desired SNR. Each point in the graphs represents the average of 3000 Monte-Carlo runs.

Figures 2-3 show results for α=1. The performance of all combined schemes is similar, with a slight advantage to Scheme I. As may be expected, the performance of the combined schemes degrades with increasing delay, while the performance of the closed-loop scheme is independent of the delay. For small delays (less than 4 time slots), the combined scheme outperforms the closed loop scheme. However, for large delays (greater than or equal to 4 time slots) the closed loop scheme performs better than the combined schemes. These observations demonstrate the importance of adjusting the weight of the open loop component.

Figures 4-5 show results for α=0.5. In contrast with ARIB's scheme, the combined schemes I and II with α =0.5 outperform the closed-loop scheme for all delays except for the maximum delay where they are comparable. Schemes I and II outperform ARIB's scheme when the delay is greater than two time slot, while the ARIB scheme is superior only for a delay of one slot. It appears therefore that Schemes I and II with α<1 are more robust with respect to time delay than the original scheme proposed by ARIB.

Figures 6-7 show results for varying α, where α varies with delay as α=1-(D-1)/6, and D is the delay in number of slots. In this case Schemes I and II outperform the both the closed-loop scheme and ARIB's scheme for all delays. Again, Schemes I and II with variable α are more robust with respect to time delay than the original scheme proposed by ARIB.

5 Conclusions

This paper demonstrates that combined closed-loop/open-loop schemes with an adjustable weight of the open loop component may lead to a significant gain in performance of the power control procedure. Furthermore, it may be desirable from network operator point of view to have the ability to vary the open-loop and closed-loop contributions to the overall power control adjustment (e.g. turn off open-loop power control).

This paper presents two new schemes for combined closed-loop/open-loop power control. In both schemes the open loop component is weighted by a parameter $0 \leq \alpha \leq 1$. In addition, this paper proposes a simple procedure to adjust α according to the delay between the uplink time-slot and the most recent downlink slot. Note that the basic idea is to weight the contributions of the open-loop and closed-loop to the power control adjustment according to their respective quality. Similar schemes can be devised by weighting the closed loop contribution only as well.

The simulation results in this paper indicate that the combined closed-loop/open-loop schemes proposed in this paper with adjustable α outperform both ARIB's combined closed-loop/open-loop scheme and closed-loop power control. In contrast with ARIB's scheme, the new schemes with adjustable α are robust with respect to the delay between the uplink time-slot and the most recent downlink slot.

Further improvements in combined closed-loop/open-loop power control can be achieved by adaptive weighting of the open-loop component (e.g. adaptive α), or adaptive weighting of both components. The delay-dependent adaptive weights can be determined by evaluating the quality of available measurements (e.g. quality of path-loss measurement can be determined by estimating the fading rate of the channel or other methods). Enhanced combined closed-loop/open-loop methods with adaptive are currently under study. Results will be presented in subsequent meetings.

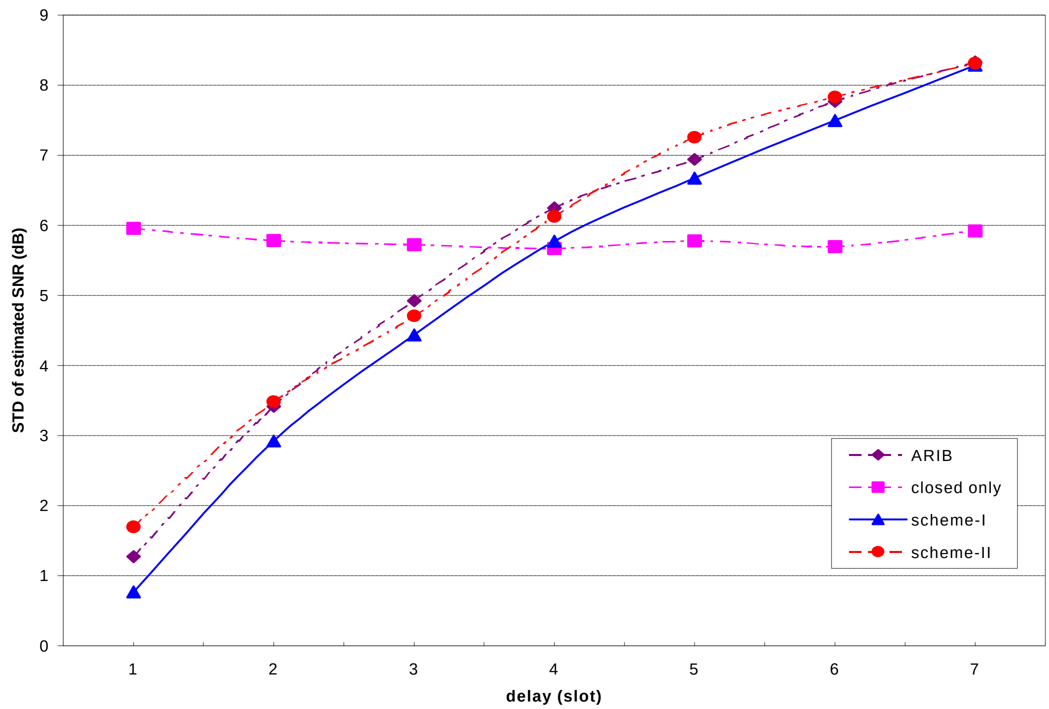

Figure 2: Standard deviation of SNR estimates as a function of delay, alpha=1

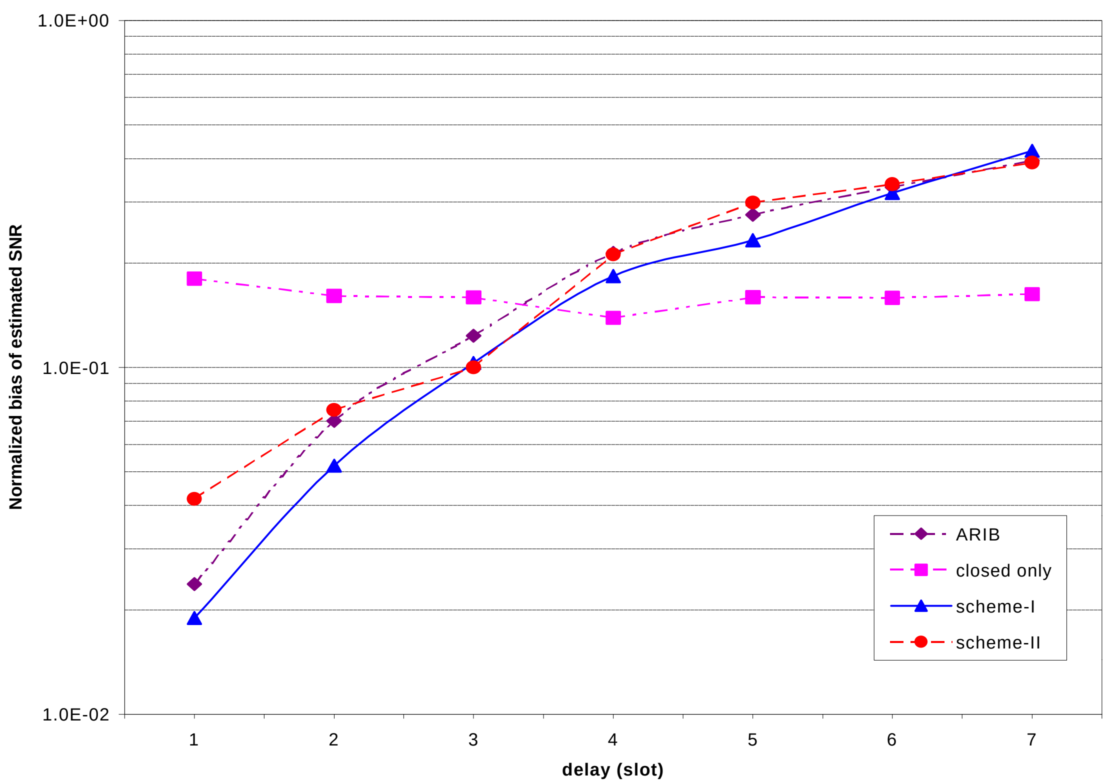

Figure 3: Normalized bias of SNR estimates as a function of delay, alpha=1

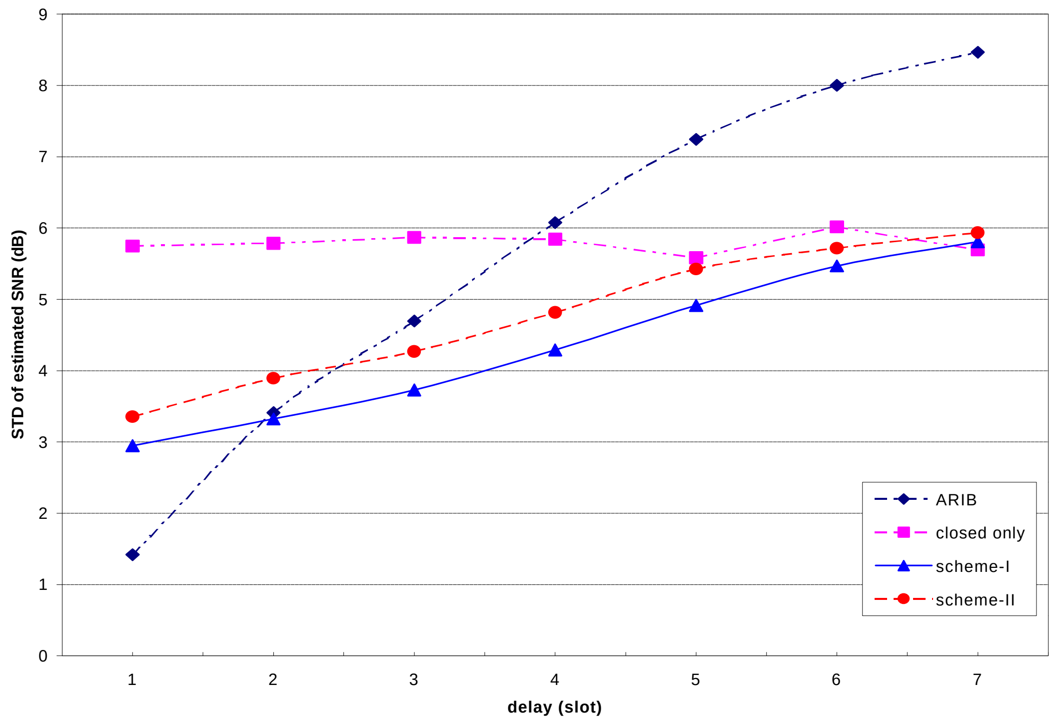

Figure 4: Standard deviation of SNR estimates as a function of delay, alpha=0.5

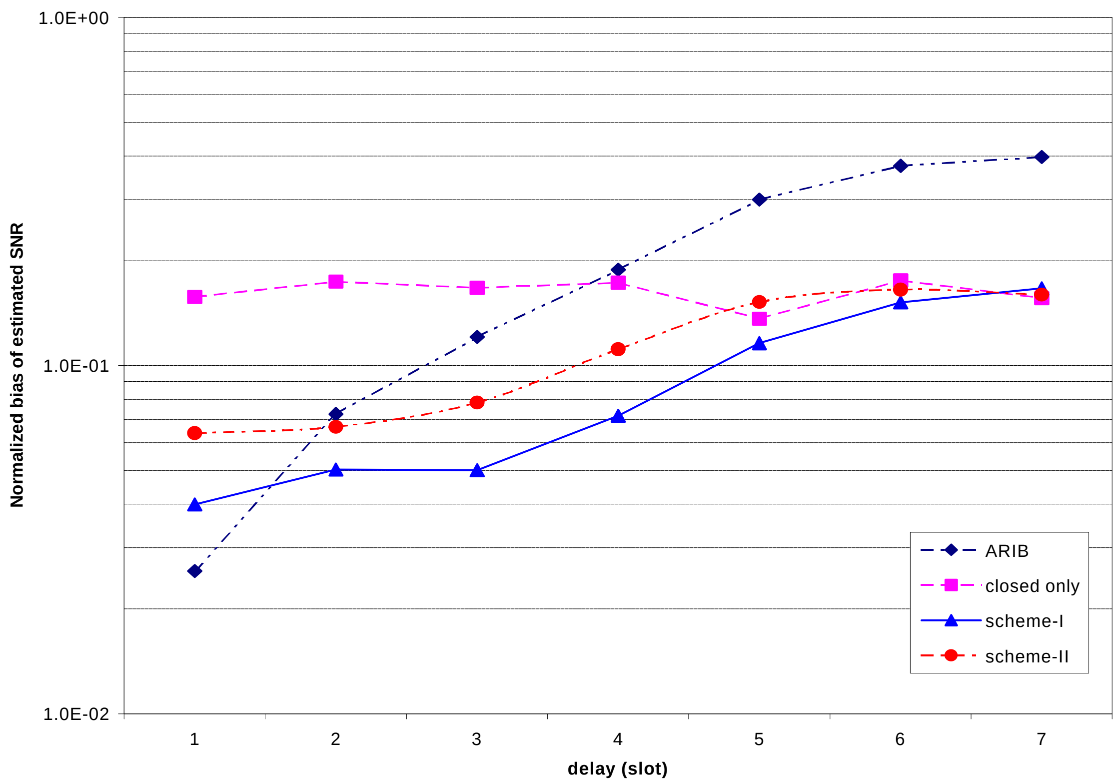

Figure 5: Normalized bias of SNR estimates as a function of delay, alpha=0.5

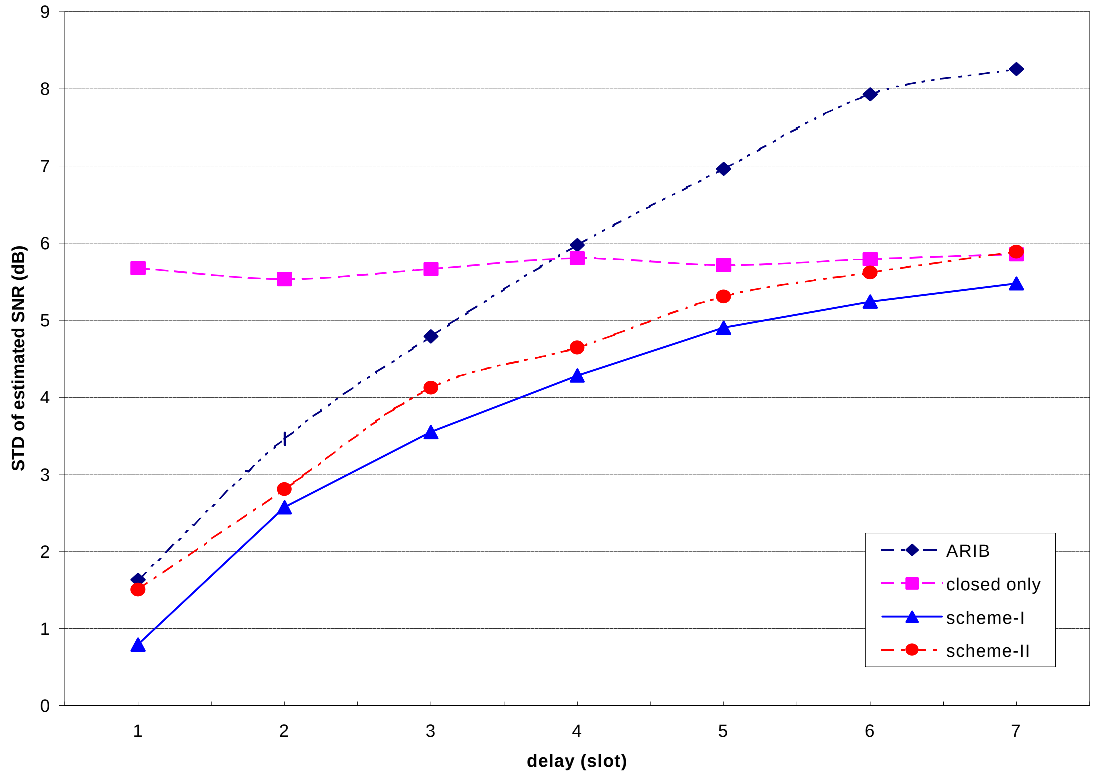

Figure 6: Standard deviation of SNR estimates as a function of delay, alpha varies with delay

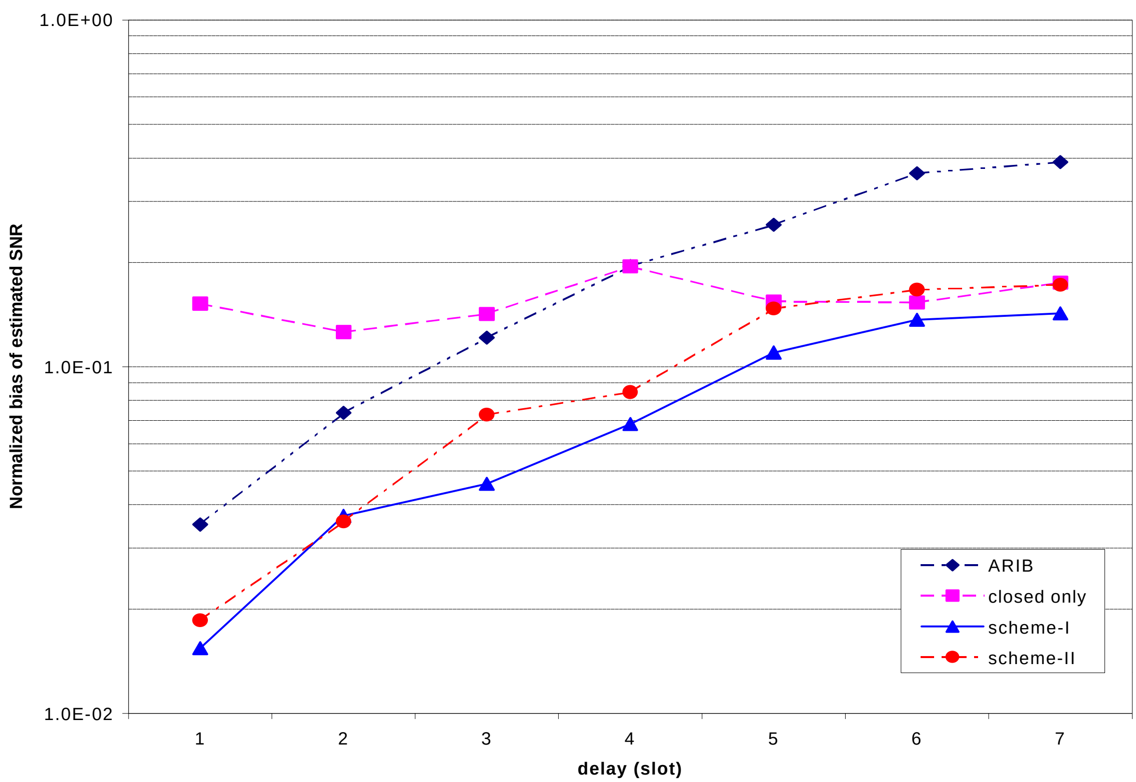

Figure 7: Normalized bias of SNR estimates as a function of delay, alpha varies with dela