Effects of power control error on the performance of the STBC-CDMA system.

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Abstract—This paper addresses the issue of acknowledging the effects on Power Control Error on a Space Time Block Coded Direct Sequence-Code Division Multiple-Access system (STBC-CDMA). Of late, many simulations and analytical work is in progress concerning the implementations of the MIMO system Concatenate with the CDMA scheme to enhance high data rate. The results mostly ignore the effects of Power Control Errors (PCE). In this paper, the effect of PCE on the performance of the STBC-CDMA system is investigated. This is done in order to display a more realistic picture of the advantage of STBC-CDMA system.

Index Terms—CDMA, STBC, Power Control Error

I. INTRODUCTION

THE Multiple Input-Multiple Output (MIMO) concept is becoming a familiar issue with communications engineers. Since the approximate 10 years of its introduction, many a research has been conducted to establish a proper and efficient way of using it. It has been shown through theoretical analysis, simulations and emulations that the use of MIMO antenna diversity does increase the throughput and data-rate for wireless communications by an interesting magnitude of order.

To take full advantage of the MIMO systems, special codes have to be used on the bits being transmitted through it. These codes exist, mainly in the form of Space Time Codes (STC) and sometimes, as Space Frequency Codes. Our interest in this paper lies with the STCs, of which there two main types namely, the Space Time Block Codes- STBC and the Space Time Trellis Codes-STTC. On comparison, the STTC has higher Bit Error Rate (BER) performance while the STBC wins its grounds on its reduced implementation complexity both in coding and decoding. The complication of the STTC arises due to the stages involved in decoding, which increases exponentially with increase in trellis steps.[2,3]. This makes the STBC a code of choice. A better overview of these STCs can be seen in [3]. A concatenation of these codes with error correcting codes is also possible and this is well documented in [3].

The MIMO antenna diversity schemes are making their ways into the multiuser environment. The combination of the MIMO and CDMA thus presents an obviously attractive package.

For this work, the space time block code as proposed in Alamouti in [1] is used as a guide to produce the multiuser STBC-CDMA system model.

It is known that power control error is one of the major problems in wireless CDMA multiuser environment [4]. This presents itself in the form of near-far effect as well as shadowing. As seen in [4], the performance of the power control algorithm depends on

- Speed of the adaptive power control system.
- Dynamic range of the transmitter
- Spatial distribution of the users
- Propagation statistics.

This paper will however not look at the individual effects of these factors but rather, at the overall effect of errors derived from improper power control on performance of the system

Assumptions made in this paper are that there is firstly, a perfect knowledge of channel gain by the MRC system used for STBC decoding along with the other assumptions made in [1] to achieve the given results. Secondly, it is assumed that the signals are undergoing fading that follow the Raleigh distribution, implying no specula component to the signals. The system is assumed to have coherent detection of the sent signal and also that antipodal modulation as in BPSK is used for the transmitted bits.

In this paper, the model for a STBC-CDMA-Alamouti two-by-one and two-by-two diversity schemes are presented in section II. Since the scheme in [1] was for a simple MIMO system, the CDMA part was incorporated. Next, the simulation setup used in obtaining the results, is explained in section III. This is followed by a discussion of results from the simulation in section-IV. This is to clearly show the true performance of a STBC-CDMA system in the presence of power control errors and thus show its effect on the system performance. A conclusion on the effect of power control error on the performance of the STBC-CDMA system is drawn in section V of the paper.

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II- SYSTEM MODEL

For this work, the space time block code as proposed by Alamouti in [1] is used. Working from Alamouti's scheme [1], the STBC proposed for the two-by-one and two-by-two are presented as adapted for a CDMA multiuser environment, with each user having a two transmitter set up and using the G_2 Alamouti STBC in [1]. We have the STBC matrix as

$$\begin{bmatrix} S_0 & S_1 \\ -\bar{S}_1 & \bar{S}_0 \end{bmatrix} \quad (1)$$

The spreading sequences for each of the K users in the system are generated using a uniform random number generator.

Considering the uplink scenario, we have the received signal as shown below.

From a single user 2by1 environment, the received signal, r(t) is given as

$$r_0 = r(t) = h_0 * S_0 + h_1 * S_1 + n_0$$
$$r_1 = r(t+T) = -h_0 * \bar{S}_1 + h_1 * \bar{S}_0 + n_1 \quad (2)$$

Where,

$$S_0 = \sqrt{E}(t) * b_0(t)$$
$$S_1 = \sqrt{E}(t) * b_1(t) \quad (3)$$

With $b_1(t)$ being the user bit to be transmitted, E being the transmitting power of the signal and h_* is the magnitude of the Raleigh channel gain effect.

In a multiuser environment, we have for user i (i=0 for reference user):

$$r_0 = r(t) = h_{0i} * S_{0i} + h_{1i} * S_{1i} + \sum_{\substack{k=0 \\ k \neq i}}^{K-1} (h_{0ki} * S_{0k} + h_{1ki} * S_{1k}) + n_0$$
$$r_1 = r(t+T) = -h_{0i} * \bar{S}_{1i} + h_{1i} * \bar{S}_{0i} + \sum_{\substack{k=0 \\ k \neq i}}^{K-1} (-h_{0ki} * \bar{S}_{1k} + h_{1ki} * \bar{S}_{0k}) + n_1 \quad (4)$$

Where $a_i(t)$ represents the Spreading sequence for user i.

After combining through the Maximum Ratio Combining (MRC) method, the estimates of the sent signals are:

$$\tilde{S}_{0i} = \bar{h}_{0i} * r_0 + h_{1i} * \bar{r}_1$$

$$\tilde{S}_{0i} = \bar{h}_{0i} * h_{0i} * S_{0i} + \bar{h}_{0i} * h_{1i} * S_{1i} + \sum_{\substack{k=0 \\ k \neq i}}^{K-1} (\bar{h}_{0i} * h_{0ki} * S_{0k} + \bar{h}_{0i} * h_{1ki} * S_{1k}) + \bar{h}_{0i} * n_0 - \bar{h}_{0i} * h_{1i} * S_{1i} + \bar{h}_{1i} * h_{1i} * S_{0i} + \sum_{\substack{k=0 \\ k \neq i}}^{K-1} (-h_{1i} * \bar{h}_{0ki} * S_{1k} + h_{1i} * \bar{h}_{1ki} * S_{1k}) + h_{1i} * \bar{n}_1$$

$$\tilde{S}_{0i} = (h_{0i}^2 + h_{1i}^2) * S_{0i} + \bar{h}_{0i} * n_0 + h_{1i} * \bar{n}_1 + \sum_{\substack{k=0 \\ k \neq i}}^{K-1} (S_{0k}(\bar{h}_{0i} * h_{0ki} + h_{1i} * \bar{h}_{1ki}) + S_{1k}(\bar{h}_{0i} * h_{1ki} - h_{1i} * \bar{h}_{0ki}) \quad (5)$$

Likewise, S_1 can be estimated to:

$$\tilde{S}_{1i} = \bar{h}_{1i} * r_0 - h_{0i} * \bar{r}_1$$

$$\tilde{S}_{1i} = \bar{h}_{1i} * h_{0i} * S_{0i} + \bar{h}_{1i} * h_{1i} * S_{1i} + \sum_{\substack{k=0 \\ k \neq i}}^{K-1} (\bar{h}_{1i} * h_{0ki} * S_{0k} + \bar{h}_{1i} * h_{1ki} * S_{1k}) + \bar{h}_{1i} * n_0 + h_{0i} * \bar{h}_{0i} * \bar{S}_{1i} - h_{0i} * \bar{h}_{1i} * S_{0i} + \sum_{\substack{k=0 \\ k \neq i}}^{K-1} (-h_{0i} * \bar{h}_{0ki} * S_{1k} + h_{0i} * \bar{h}_{1ki} * \bar{S}_{0k}) + h_{1i} * \bar{n}_1$$

$$\tilde{S}_{1i} = (h_{0i}^2 + h_{1i}^2) * S_{1i} + \bar{h}_{1i} * n_0 - h_{0i} * \bar{n}_1 + \sum_{\substack{k=0 \\ k \neq i}}^{K-1} (S_{0k}(\bar{h}_{1i} * h_{0ki} - h_{0i} * \bar{h}_{1ki}) + S_{1k}(\bar{h}_{1i} * h_{1ki} + h_{0i} * \bar{h}_{0ki}) \quad (6)$$

On substituting the values of S_0 and S_1,

$$\tilde{S}_{0i} = (h_{0i}^2 + h_{1i}^2) * \sqrt{E} * a_i(t) * b_{0i}(t) + \bar{h}_{0i} * n_0 + h_{1i} * \bar{n}_1 + \sum_{\substack{k=0 \\ k \neq i}}^{K-1} \begin{pmatrix} \sqrt{E} * a_k(t) * b_{0k}(t) * (\bar{h}_{0i} * h_{0ki} + h_{1i} * \bar{h}_{1ki}) \\ + \sqrt{E} * a_k(t) * b_{1k}(t) * (\bar{h}_{0i} * h_{1ki} - h_{1i} * \bar{h}_{0ki}) \end{pmatrix} \quad (7)$$

$$\tilde{S}_{1i} = (h_{0i}^2 + h_{1i}^2) * \sqrt{E} * a_i(t) * b_{1i}(t) + \bar{h}_{1i} * n_0 - h_{0i} * \bar{n}_1 + \sum_{\substack{k=0 \\ k \neq i}}^{K-1} \begin{pmatrix} \sqrt{E} * a_k(t) * b_{0k}(t) * (\bar{h}_{1i} * h_{0ki} - h_{0i} * \bar{h}_{1ki}) \\ + \sqrt{E} * a_k(t) * b_{1k}(t)(\bar{h}_{1i} * h_{1ki} + h_{0i} * h_{0ki}) \end{pmatrix} \quad (8)$$

For user i, CDMA decoding is done by multiplying the signal with the reference user's spreading sequence as:

$$\tilde{S}_{0i} * a_i(t) = (h_{0i}^2 + h_{1i}^2) * \sqrt{E} * b_{0i}(t) + \bar{h}_{0i} * n_0 * a_i(t) + h_{1i} * \bar{n}_1 * a_i(t) + \sum_{\substack{k=0 \\ k \neq i}}^{K-1} \begin{pmatrix} \sqrt{E} * R_{ki}(t) * b_{0k}(t) * (\bar{h}_{0i} * h_{0ki} + h_{1i} * \bar{h}_{1ki}) \\ + \sqrt{E} * R_{ki}(t) * b_{1k}(t) * (\bar{h}_{0i} * h_{1ki} - h_{1i} * \bar{h}_{0ki}) \end{pmatrix} \quad (9)$$

$$\tilde{S}_{1i} * a_i(t) = (h_{0i}^2 + h_{1i}^2) * \sqrt{E} * b_{1i}(t) + \bar{h}_{1i} * n_0 * a_i(t) - h_{0i} * \bar{n}_1 * a_i(t) + \sum_{\substack{k=0 \\ k \neq i}}^{K-1} \begin{pmatrix} \sqrt{E} * R_{ki}(t) * b_{0k}(t) * (\bar{h}_{1i} * h_{0ki} - h_{0i} * \bar{h}_{1ki}) \\ + \sqrt{E} * R_{ki}(t) * b_{1k}(t)(\bar{h}_{1i} * h_{1ki} + h_{0i} * h_{0ki}) \end{pmatrix} \quad (10)$$

Where, R_{1k0} and R_{2k0} are the correlation factors between the spreading sequence of the reference user and that of the interfering user.

These values are thus passed on to the Maximum Likelihood Detector to make a hard decision on the decoding of the estimates into bit forms.

Going through the same process for a two-by-two, it can be seen that

$$\tilde{S}_{0i} * a_i(t) = (h_{0i}^2 + h_{1i}^2 + h_{2i}^2 + h_{3i}^2) * \sqrt{E} * b_{0i}(t) + \bar{h}_{0i} * n_0 * a_i(t) + h_{1i} * \bar{n}_1 * a_i(t) + \bar{h}_{2i} * n_2 * a_i(t) + h_{3i} * \bar{n}_3 * a_i(t) + \sum_{\substack{k=0 \\ k \neq i}}^{K-1} \begin{pmatrix} \sqrt{E} * R_{ki}(t) * b_{0k}(t) * (\bar{h}_{0i} * h_{0ki} + h_{1i} * \bar{h}_{1ki} + \bar{h}_{2i} * h_{2ki} + h_{3i} * \bar{h}_{3ki}) \\ + \sqrt{E} * R_{ki}(t) * b_{1k}(t) * (\bar{h}_{0i} * h_{1ki} - h_{1i} * \bar{h}_{0ki} + \bar{h}_{2i} * h_{3ki} - h_{2i} * \bar{h}_{3ki}) \end{pmatrix} \quad (11)$$

$$\tilde{S}_{1i} * a_i(t) = (h_{0i}^2 + h_{1i}^2 + h_{2i}^2 + h_{3i}^2) * \sqrt{E} * b_{1i}(t) + \bar{h}_{1i} * n_0 * a_i(t) - h_{0i} * \bar{n}_1 * a_i(t) + \bar{h}_{3i} * n_2 * a_i(t) - h_{2i} * \bar{n}_3 * a_i(t) + \sum_{\substack{k=0 \\ k \neq i}}^{K-1} \begin{pmatrix} \sqrt{E} * R_{ki}(t) * b_{0k}(t) * (\bar{h}_{1i} * h_{0ki} - h_{0i} * \bar{h}_{1ki} + \bar{h}_{3i} * h_{2ki} - h_{2i} * \bar{h}_{3ki}) \\ + \sqrt{E} * R_{ki}(t) * b_{1k}(t)(\bar{h}_{1i} * h_{1ki} + h_{0i} * h_{0ki} + \bar{h}_{3i} * h_{3ki} + h_{2i} * h_{2ki}) \end{pmatrix} \quad (12)$$

At this stage, the information for the reference user is extracted. This is simply done using the matched filter in the CDMA detection scheme interpolated into the MRC decoding scheme.

The system models that were presented in equations (9) to (10) assumed a perfect power control. That is why the received energy ($\sqrt{E} = \sqrt{PT}$ where P is the transmitted power and T is the bit duration) is taken to be the same for all users. With power control error, the received can be modeled as $\sqrt{(P\Delta P)T}$ [4] where ΔP is the power control error. ΔP can be modeled as a log-normal distribution as seen below[4]:

$$\Delta P = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left(\frac{-\left[\log\left(x/m\right)\right]^2}{2\sigma^2} \right) \qquad (13)$$

III- SIMULATION SETUP

Bits transmitted were modulated using the BPSK along with Alamouti's G_2 STBC and a DS-CDMA encoder.

To show the effects of Power Control Error on the performance of the STBC CDMA in a multiuser environment, the two-by-one and two-by-two MIMO-STBC diversity schemes were studied. The channel gain was of Rayleigh distribution. The power control error on each user's signal is assumed to follow the log-normal distribution as seen in [4].

For this work, a 100,000 bits transmission session was simulated. Perfect knowledge of the Rayleigh fading channel gain was assumed. The simulation was conducted for 10 and 15 user scenarios. The DS-CDMA coding gain of 63 was used. Since the system is simulated to be of synchronous reception, the bits were perfectly aligned.

In Figure 1, the BER for Signal to Noise Ratio in decibels (SNR (dB)) ranging from 0dB to 29db is shown. In this figure, the variance of the log-normally distributed PCE was zero. Next, for figures 2 to 5, a similar simulation was conducted with the variance being 5, 10, 15 and 20 respectively.

In Figure 6, a more specific approach is taken by focusing on the performance of the system at a particular SNR of 10db. The corresponding BER for the changing values of the variance of the log-normally distributed PCE is shown.

IV- RESULTS AND DISCUSSION OF RESULTS:

As popular as the MIMO system is getting, there is not enough knowledge about it as yet. The issue of power control is of utter importance in any multiuser environment. The system model as shown above is thus implemented by simulation to study the effects of PCE on the performance of the system.

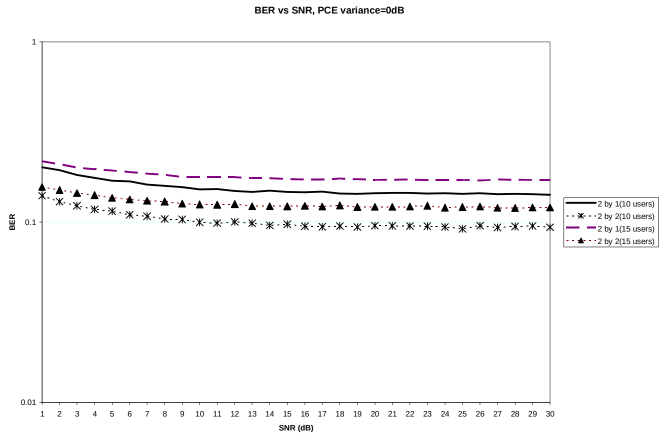


Figure 1 Performance of 2x1 and 2x2 for PCE variance=0db. Coding gain=63.

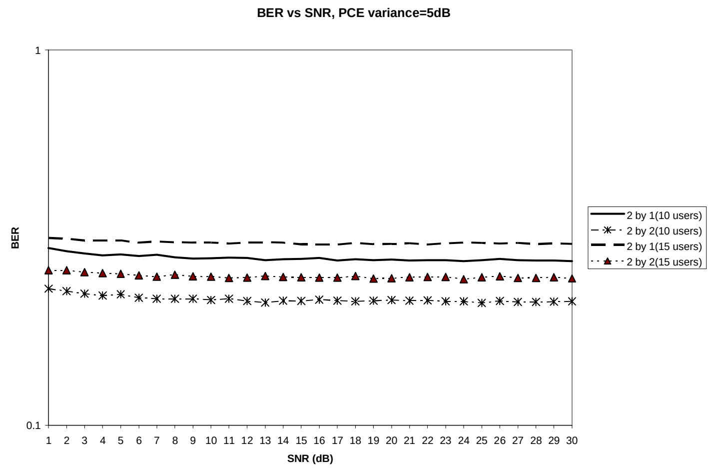
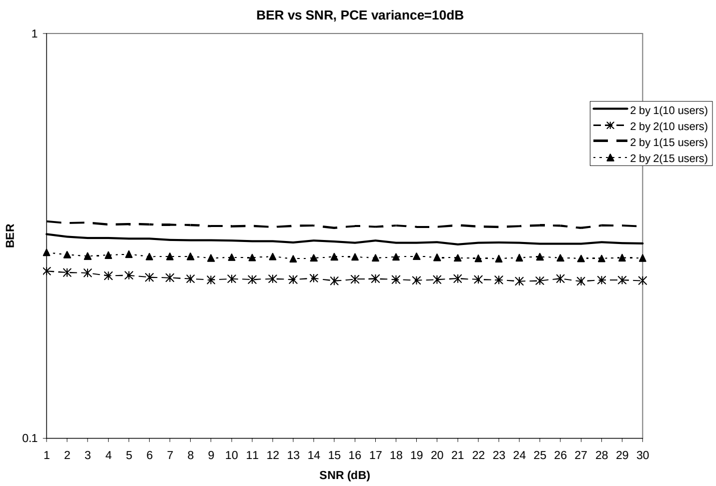


Figure 2 Performance of 2x1 and 2x2 for PCE variance=5db. Coding gain=63.
Figure 3 Performance of 2x1 and 2x2 for PCE variance=10db. Coding gain=63.



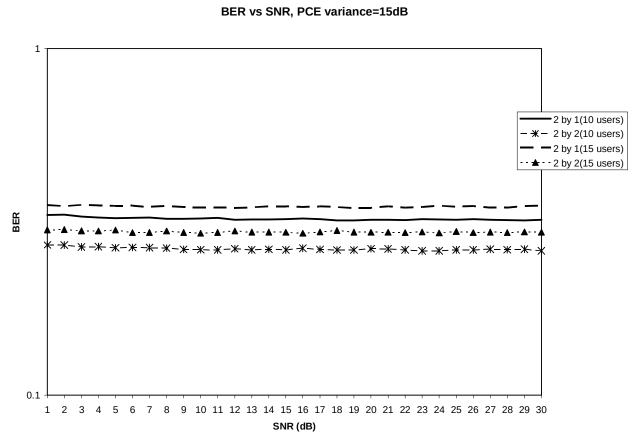


Figure 4 Performance of 2x1 and 2x2 for PCE variance=15db. Coding gain=63.

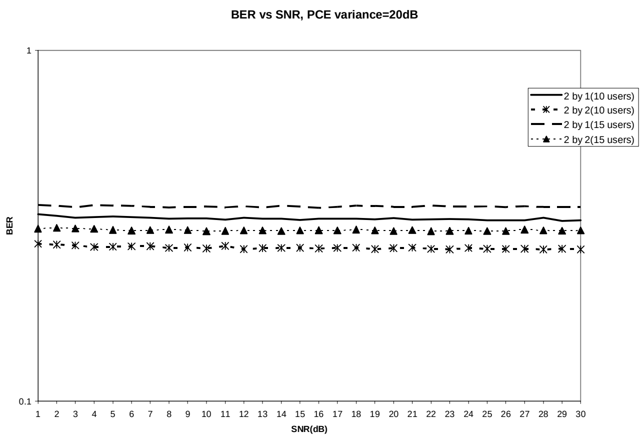


Figure 5 Performance of 2x14 and 2x2 for PCE variance=20db. Coding gain=63.

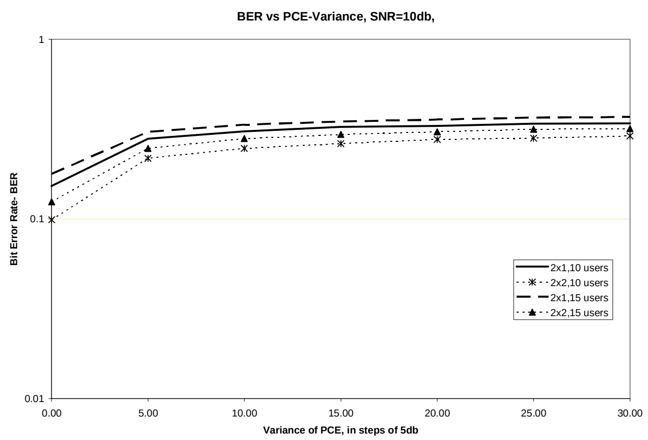


Figure 6- Performance of system at SNR=10db with changing variance of PCE. Coding gain=63

As seen above, the first case in Figure 1 had a PCE whose variance is zero. This implied a scenario where the PCE is not present and thus a perfect power control is in place. The performance of the two diversity orders studied is shown with the two-by-two having a better performance than the two-by-one. This is expected as the diversity order is greater.

On increasing the variance of the PCE as seen in Figure 2, the performance of both reduced and the effect of the increase in SNR can be seen to lessen. A further increase in the variance gave a more severe but similar situation. Also the performance of the two diversity orders started moving towards a common point and although this can not be clearly seen on figures 1 to 5, figure 6 showed a more explicit graph of what happens as the variance of the PCE was increased. The overall performance of the system when the PCE variance is high is seen to be much worse than when there is a perfect power control. The simulation was performed for a multiuser STBC CDMA environment consisting of 10 and 15 users in a single cell scenario.
From the graphical plots above, the various performance of the STBC-CDMA system utilizing the STBC as explained in [1,2,3], can be seen to decrease in a multiuser environment with increase in the variance of the log-normally distributed Power Control Error. It is also noted that the degradation in performance is such that the advantage gained by the antenna diversity is lost as the variance for the PCE increases. A close look at fig. 6 clearly shows the two lines approaching each other as the PCE intensifies.

Of note is the rate at which the BER performance degrades with the increase in PCE. At zero and low variance, a slight improvement can still be noted with the increase in SNR. At high variance PCE, the performance is seen to be stagnant with increase in SNR.

V- CONCLUSION

It can be concluded that the diversity gain is nullified by lack of proper power control algorithm implementation in a STBC-CDMA system. This can be clearly seen from the way the two lines approach each other as the variance of the PCE is increased in fig. 6.

Also, as the PCE get more severe, that is, as its variance increases, the increase in SNR of the signals looses its effect on system performance.

These observations lead to the conclusion that the implementation and integration of Power Control algorithms is a necessity if one is to benefit from the advantages associated with the MIMO STBC antenna diversity in a multiuser CDMA environment.

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