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Abstract	Closed loop STC precoding to improve performance with limited feedback
Purpose	Discussion and Adoption
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Closed-loop Precoding for STC

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1. Introduction

The current IEEE 802.16e-D5 amendment suggests the application of complex weights to all four antennas for the transmission from 4-antenna BS in the AMC permutation zone. However, this mode of operation requires an unnecessary large amount of feedback from the MSS to the BS to inform the BS about the settings of these four weights.

In this contribution, first we analytically show how exactly the same received signal-to-noise ratio can be achieved with a significant reduction in the amount of the required feedback information and delay. Then we show how even further reduction of the feedback information and delay (which improves performances at non-zero Doppler frequencies) can be achieved by an appropriate quantization of the feedback information. This contribution also contains the text proposal.

2. The 4-antenna STC with rate 1

In the current specification, section 8.4.8.3.5 describes the STC scheme with the AMC permutation zone using the following matrix:

$$A = \begin{bmatrix} s_1 w_0 & -s_2^* w_0 & 0 & 0 \\ s_2 w_1 & s_1^* w_1 & 0 & 0 \\ 0 & 0 & s_3 w_2 & -s_4^* w_2 \\ 0 & 0 & s_4 w_3 & s_3^* w_3 \end{bmatrix} \quad (1)$$

The matrix (1) defines the transmission format with the row index indicating the antenna number and column index indicating the subchannel symbol time (2 symbols per entry), the entrees defines the transmission from a subchannel used for this transmission configuration.

It is well known [1], that the Alamouti space time code using a Maximum Likelihood receiver can be described as an equivalent SISO channel. With this notation, the Alamouti space time code has an SNR after space time decoding that is dependent on the channel coefficients in the following way

$$SNR_{A1} \propto \sum_{r=1}^{N_r} |w_0|^2 |h_{r1}|^2 + |w_1|^2 |h_{r2}|^2 \quad (2)$$

$$SNR_{A2} \propto \sum_{r=1}^{N_r} |w_2|^2 |h_{r3}|^2 + |w_3|^2 |h_{r4}|^2 \quad (3)$$

where h_{rt}, t=1,2 are the channel coefficients from transmitter antenna t to receiver antenna r for subchannel 1 and h_{rt}, t=3,4 are the channel coefficients from transmitter antenna t to receiver antenna r for subchannel 2 . It can thus be seen in (2),(3) that the phase information of the weights w_0, w_1, w_2, w_3 are not present in the expressions for the SNR and therefore, receive SNR cannot be improved by any adjustment of these phases. Hence, the feedback of phase information in this mode is redundant and consumes unnecessary feedback bandwidth.

Due to the constant power constraint $|w_0|^2 + |w_1|^2 + |w_2|^2 + |w_3|^2 = K$, and with the weight amplitudes quantized to two discrete levels as in IEEE 802.16e-D5, only three feedback bits are required to uniquely set all the four weights in (1). This is a considerable reduction in required amount of feedback data.

3. The 4-antenna STC with rate 2

Section 8.4.8.3.5 describes the STC scheme with the AMC permutation zone with rate 2 using the following matrix:

$$B = \begin{bmatrix} s_1 w_0 & -s_2^* w_0 & s_5 w_0 & -s_7^* w_0 \\ s_2 w_1 & s_1^* w_1 & s_6 w_1 & -s_8^* w_1 \\ s_3 w_2 & -s_4^* w_2 & s_7 w_2 & s_5^* w_2 \\ s_4 w_3 & s_3^* w_3 & s_8 w_3 & s_6^* w_3 \end{bmatrix} \qquad (4)$$

With this mode, there will be mutual interference between the space time encoded data streams transmitted from the two pairs of antennas, and at least two antennas are required at the MSS to separate the signals. However, as will be shown below, due to the special structure of the Alamouti space time code using a minimum mean squared error receiver, the SNR for the two substreams does not depend on the absolute values of the phases of the four antenna weights w_0, w_1, w_2 and w_3, but rather on a linear combination of these phases.

Hence, the exactly the same SNR can be obtained if the phases of arbitrary three antenna weights are set to zero, and if the phase of the remaining forth antenna weight is set to an appropriate value. This means that only the phase information of *one* of the four antenna weights needs to be feed back to the receiver, which will lead to a significant reduction in the feedback bandwidth and delay.

Assume that the weights applied to the four transmitted signals are composed of the magnitude and phase as

$$w_i = a_i e^{j\alpha_i} \quad i = 1,..,4\,. \qquad (5)$$

Using a linear MMSE receiver to detect the two data streams on each subchannel (the symbols s_1 to s_4 in subchannel 1 and symbols s_5 to s_8 in subchannel 2), the SNR for the two data streams can be written as proportional to (the analysis is assuming subchannel 1, an equivalent analysis can be made for subchannel 2)

$$SNR_{B1} \propto K_1 \left(a_2^2 |h_{12}|^2 + a_1^2 |h_{21}|^2 + a_1^2 |h_{11}|^2 + a_2^2 |h_{22}|^2 \right) - 2\varepsilon_1 \operatorname{Re}\{\Lambda\} \qquad (6)$$

$$SNR_{B2} \propto K_2 \left(a_3^2 |h_{13}|^2 + a_3^2 |h_{23}|^2 + a_4^2 |h_{14}|^2 + a_4^2 |h_{24}|^2 \right) - 2\varepsilon_2 \operatorname{Re}\{\Lambda\} \qquad (7)$$

where

$$\begin{aligned} \Lambda = {} & a_1 a_2 a_3 a_4 \left(e^{j\Delta} \left(h_{12} h_{21} h_{14}^* h_{23}^* - h_{12} h_{21} h_{13}^* h_{24}^* \right) + e^{-j\Delta} \left(h_{11}^* h_{22}^* h_{13} h_{24} - h_{11}^* h_{22}^* h_{14} h_{23} \right) \right) + \\ & + a_1 a_3 h_{11}^* h_{21} h_{13} h_{23}^* + a_1 a_4 h_{11}^* h_{21} h_{14} h_{24}^* + a_2 a_4 h_{12} h_{22}^* h_{14}^* h_{24} + a_2 a_3 h_{12} h_{22}^* h_{13}^* h_{23} \end{aligned} \qquad (8)$$

and

$$\varepsilon_1 = \frac{1}{\sigma^2 \left(a_3^2 |h_{13}|^2 + a_4^2 |h_{14}|^2 + a_3^2 |h_{23}|^2 + a_4^2 |h_{24}|^2 + \sigma^2 \right)}, \qquad (9)$$

$$\varepsilon_2 = \frac{1}{\sigma^2 \left(a_1^2 |h_{11}|^2 + a_2^2 |h_{12}|^2 + a_1^2 |h_{21}|^2 + a_2^2 |h_{22}|^2 + \sigma^2 \right)}, \qquad (10)$$

$$K_1 = \frac{1}{\sigma^2} + \varepsilon_1 \sigma^2\,, \qquad (11)$$

$$K_2 = \frac{1}{\sigma^2} + \varepsilon_2 \sigma^2\,, \qquad (12)$$

$$\Delta = \alpha_1 + \alpha_2 - \alpha_3 - \alpha_4 . \quad (13)$$

Several things can now be noted from the expressions above:

- Both SNR's given by (6) and (7) can be maximized *concurrently* by finding the optimum angle Δ.
- By adjusting the weight amplitudes, a_1, a_2, a_3, a_4, the SNR's in (6),(7) will change. However, due to the cross-interference terms, it is not in general possible to achieve the highest achievable SNR for both streams simultaneously for one unique set of weights a_1, a_2, a_3, a_4. If more power is put on one of the substreams, the other one will generally suffer a lower SNR.
- The value Δ depends only on the linear combination of the phases of weights according to (13). We can thus without loss of generality set the combining coefficients for α_2, α_3 and α_4 to be equal to zero and adjust the SNR for both substreams with $\Delta = \alpha_1$ only. This gives a significant reduction in the amount of feedback since only the phase weight of a single antenna needs to be feed back to the transmitter.
- Due to the constant power constraint, $a_1^2 + a_2^2 + a_3^2 + a_4^2 = K$ must hold, so it is only necessary to feed back information about three of the weight amplitudes and then the fourth follows directly from this power constraint. This leads to a further reduction in the amount of required feedback.

The current proposal for the closed-loop STC precoding is to use the weights from the latest 802.16e/D5 specification. According to that solution, 5 bits feedback information is required for each antenna, 1 bit for the amplitude information, and 4 bits for the phase information. Hence, a total of 20 feedback bits are needed to update all antenna weights.

Based on the findings shown above, exactly the same SNR can be achieved by transmitting 7 feedback bits, where 4 bits are for the phase information (required for just 1 weight), and 3 bits are required for the amplitude information. So the amount of feedback bits to update all antenna weights is reduced by almost a factor of 3.

To further reduce, i.e. minimize the amount of feedback, with almost negligible loss in the received SNR (as it is shown by simulations), we propose to quantize the phase information to 4 values. In that way, 2 bits for the phase information are required, and with the 3 bits for the amplitude information, we come up to the total of 5 required feedback bits for each update of the precoding weights for all 4 antennas. The amount of feedback is thus minimized to be contained in a single feedback payload entity of 5 bits. We shall refer to this solution as “minimum feedback” solution.

To compare the performances of the current precoding solution with the other solutions with reduced feedback discussed above, for several discussed feedback configuration we have performed Monte-Carlo evaluations of the raw bit error rate as function of the received SNR. We have assumed BPSK modulation in quasi-static i.i.d Rayleigh fading channel with two receive antennas. The results can be seen in Figure 1~~Figure 1~~.

The adaptation of the weight amplitudes in the SNR expressions (6),(7) can lead to conflicting adaptation criterions due to the fact that an increase of one of the substream's SNR, eventually gives a decrease of the other substream's SNR. Therefore, these two substream SNR's are aimed to be as equal as possible and concurrently also as high as possible. Therefore, the antenna weights are selected to maximize the smallest of the SNR of the two substreams. The feedback delay is assumed to be zero for all evaluated solutions.

As it can be seen in Figure 1~~Figure 1~~, the minimum feedback solution results in negligible raw bit error rate degradation compared to the current STC precoding solution. On the other side, as the current solution requires 4 times more feedback data than the minimized feedback solution, its performances in terms of coded bit error rate and block error rate will be significantly worse than for the minimum feedback solution.

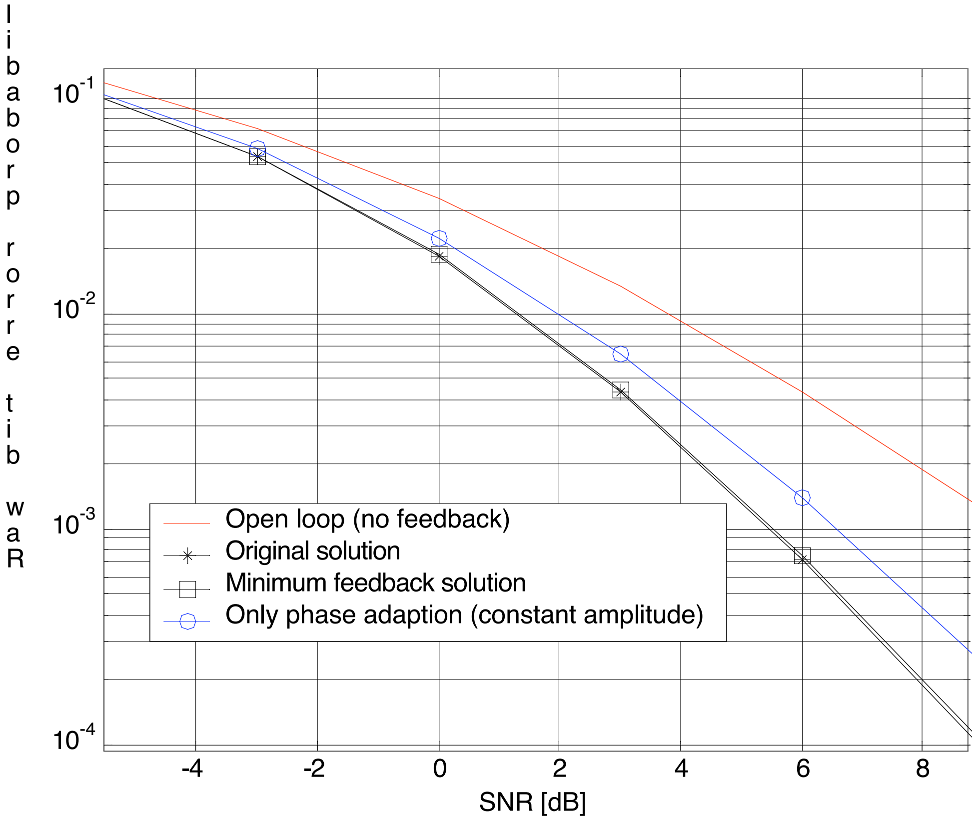

Figure 1 **Performances of closed loop precoded STC with several different feedback schemes on quasi-static flat Rayleigh fading channel.**

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~~4.~~2. Proposed text changes

[Add the following text into section 8.4.8.3.5]

When the AMC permutation zone is chosen, BS may further enhance the system performance by multiplying complex weights to antennas as follows;

$$A = \begin{bmatrix} s_1 w_0 & -s_2^* w_0 & 0 & 0 \\ s_2 w_1 & s_1^* w_1 & 0 & 0 \\ 0 & 0 & s_3 w_2 & -s_4^* w_2 \\ 0 & 0 & s_4 w_3 & s_3^* w_3 \end{bmatrix}$$

$$B = \begin{bmatrix} s_1 w_0 & -s_2^* w_0 & s_5 w_0 & -s_7^* w_0 \\ s_2 w_1 & s_1^* w_1 & s_6 w_1 & -s_8^* w_1 \\ s_3 w_2 & -s_4^* w_2 & s_7 w_2 & s_5^* w_2 \\ s_4 w_3 & s_3^* w_3 & s_8 w_3 & s_6^* w_3 \end{bmatrix}$$

$$C = \begin{bmatrix} s_1 w_0 \\ s_2 w_1 \\ s_3 w_2 \\ s_4 w_3 \end{bmatrix}$$

The weights w_0, w_1, w_2 and w_3 are defined by the 5 bits in the payload $b_4 b_3 b_2 b_1 b_0$ as follows. The bits b_0,b_1 and b_2 determines the absolute value of the weight for antenna 0,1 and 2.

b_0	b_1	b_2	w_0	w_1	w_2
0	0	1	$\sqrt{1/2}$	$\sqrt{1/2}$	$\sqrt{2}$
0	1	0	$\sqrt{1/2}$	$\sqrt{2}$	$\sqrt{1/2}$
0	1	1	$\sqrt{1/2}$	$\sqrt{2}$	$\sqrt{2}$
1	0	0	$\sqrt{2}$	$\sqrt{1/2}$	$\sqrt{1/2}$
1	0	1	$\sqrt{2}$	$\sqrt{1/2}$	$\sqrt{2}$
1	1	0	$\sqrt{2}$	$\sqrt{2}$	$\sqrt{1/2}$
All others			unused		

The weight w_3 is real and determined from $\sum_{i=0}^{3} |w_i|^2 = 5$. The bits b_3 and b_4 determines the phase of w_0 as $\arg(w_0) = \alpha_0$ in matrix B as follows

b_3	b_4	α_0
0	0	$\pi/2$
0	1	π
1	0	0
1	1	$-\pi/2$

In matrix A, b_3 and b_4 are unused and set to $b_3 = 0$ and $b_4 = 0$.

~~5.~~3. References

[1] S.Sandhu and A.Paulraj, "Space Time Block Codes: A capacity Perspective", IEEE Communication Letters, vol.4 no.12, pp.384-386, Dec 2000.