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Re:	2nd Call for Contribution on Project 802.16m System Description Document (SDD) issued on 2007-12-17 (http://ieee802.org/16/tgm/docs/80216m-07_47.pdf)
Abstract	Introduce the basis of non-linear pre-coding and propose new TLVs.
Purpose	For discussion and approval by IEEE 802.16m TG
Notice	
Release	
Patent Policy	

Proposal on Multi-user MIMO Precoding Considerations of IEEE 802.16m

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Introduction

This document is provided in response to the 2nd Call for Contribution on Project 802.16m System Description Document (SDD) issued on 2007-12-17 (http://ieee802.org/16/tgm/docs/80216m-07_47.pdf) to propose a consideration of multiple access and multi antenna techniques.

In time-division duplexed (TDD) systems, channel estimates on the uplink transmission might be utilized at the base station to employ precoding on the downlink. A multiple antenna base station can transmit spatially multiplexed streams over shared frequency resources. This can be a single-user (SU-MIMO) transmission, when all spatial streams are allocated to a single user, or a multi-user (MU-MIMO) transmission, if multiple users are served.

We describe a MU-MIMO technique that bases on Channel Inversion precoding by applying non-linear Vector Perturbation precoding.

Description of Vector Perturbation Channel Inversion Precoding

Channel Inversion (CI) precoding overcomes the changes made by the channel during the transmission by applying the Moore-Penrose pseudoinverse of the channel at the transmitter side, i.e., the data vector is precoded in order to remove inter-user interference. The basic assumption at this point is therefore perfect channel state information (CSI). A drawback of CI precoding is the increase of the transmit power [1]. Prior to transmission, the precoded signal has to be scaled in order to normalise the transmit power according to the restrictions of the base station. The normalisation factor is assumed to be known at the users' side, as they have to scale their receive signal.

The normalisation factor is often very large because of the large singular values of the precoding matrix, i.e., of the pseudoinverse of the channel matrix [1,3]. This causes noise amplification at the receiver side.

One way to overcome this is to ensure the transmitted data vector does not lie along the singular values of the pseudoinverse [1]. The idea is to allow the data vector to be perturbed by a complex integer vector, which can reduce the transmit power increase and will result in a better normalisation factor, and overall performance of the downlink transmission. This technique is called Vector Perturbation (VP) precoding. The perturbation operation can be made undone at the receiver side by a simple modulo function. A block diagram of the VP precoding can be seen in Figure 1.

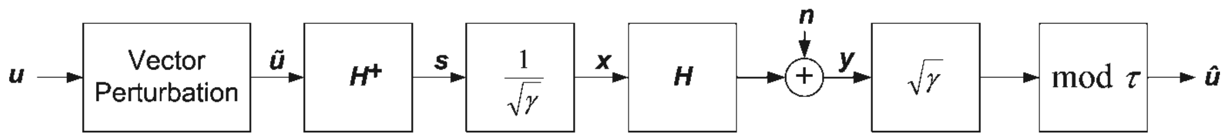

Figure 1: Block diagram of Vector Perturbation precoding

Finding the optimal perturbation vector is an integer-lattice least-squares problem, for which there exist a number of exact and approximate algorithms. For example the Sphere Encoder (cf. references contained in [1]) will calculate the optimal perturbation vector, but will also have a high complexity. An approximation can be calculated with the LLL Algorithm [2] by means of lattice-reduction-aided closest-point-approximation [4], but any other algorithm to find a suitable perturbation vector can be applied.

A detailed description of Vector Perturbation non-linear precoding can be found in the appendix.

Performance study

The performance of the proposed non-linear precoding technique Vector perturbation (VP) has been studied by means of both Sphere Encoding (SE VP) [1] and Lattice-reduction-aided closest-point-approximation (LLL VP) [4]. We compare the results with linear Channel Inversion (CI) precoding.

We consider a multi-antenna downlink with a Gaussian MIMO channel. We assume a base station having $n_T = 4$ transmit antennas, and K=4 users equipped with one receive antenna each. We further assume perfect channel knowledge at the transmitter. In each frame, $n_S = 4$ spatial streams are being transmitted to the users, each per one user.

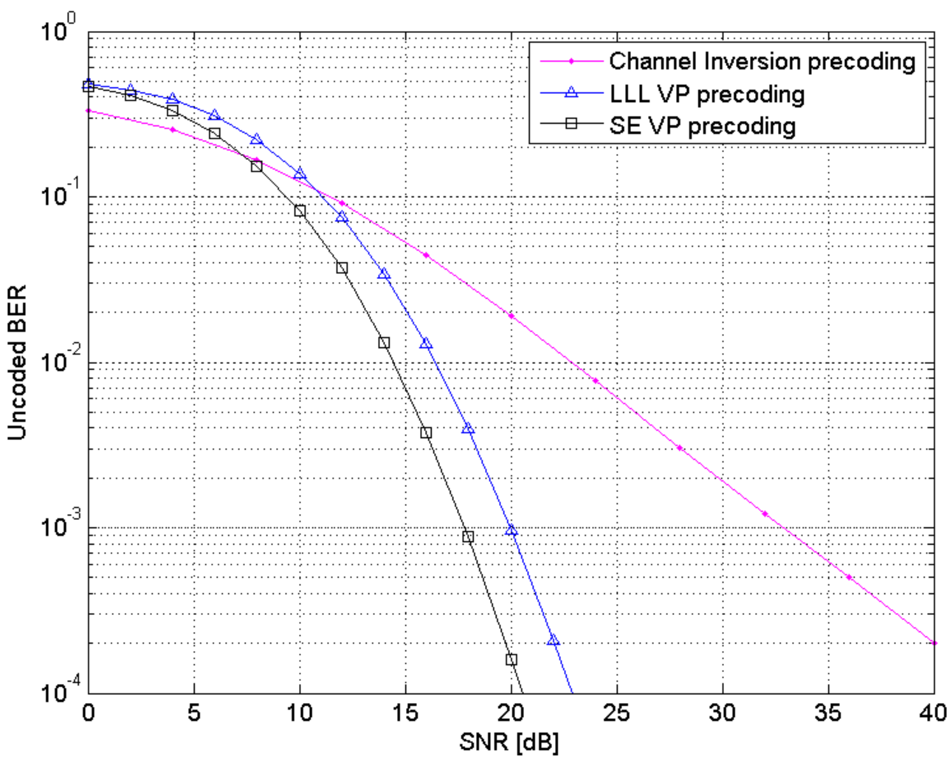

Figure 2: Uncoded Bit Error Rate of a QPSK transmission, $n_T = 4$, $K = 4$

Figure 2 shows the average performance of an uncoded QPSK transmission for all the four users. The gain in terms of BER performance between linear Pseudoinverse precoding and VP is evident. We can further observe a performance gap of 2 dB between SE VP and LLL VP precoding.

Conclusion

Vector Perturbation Channel Inversion precoding can overcome the drawback of Channel Inversion precoding, a possibly very large transmit power normalisation factor. The proposed technique can dramatically increase the performance of the downlink transmission. The implementation into the system is optional, but requires the user terminals to deal with the non-linear constellation shift employed at the transmitter side. Therefore, the user terminals need to be able to carry out the optional modulo operation if necessary. This will provide the possibility of improving the downlink transmission.

We therefore propose to implement an optional modulo function at the SSs, which can remove the constellation shift effect of non-linear precoding. Furthermore we propose new TLVs for the purposes of firstly informing the BS whether a SS can carry out a modulo operation, and secondly indicating to the user whether a modulo operation has to be carried out in order to receive the current frame.

~~~~~~~~~~~~~~~~~~~~~~ **Text input start** ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

[Insert the following sections and text in SDD]

xxx. Multiuser MIMO

xxx.y. Support of modulo operation

SS shall have modulo operation capability to support multiuser MIMO transmission. The capability shall be indicated through REG-RSP.

BS shall support modulo operation. BS shall be informed by SS of the capability and allocate MS/SS accordingly.

xxx.z. MU-MIMO channel estimation

BS shall provide both implicit and explicit channel estimation in TDD. BS shall support explicit channel estimation in FDD.

[Authors' comments: This contribution suggests adding new capabilities encodings TLV into RNG-REQ and REG-RSP message. This is created dynamically from each access SSs to BS to help BS effectively operating SDMA burst to the designated SSs.

yyy. TLV Encodings

yyy.x. SS capabilities encodings

[Insert new subclauss yyy.x.yz]

yyy.x.yz. Modulo capability support

Name	Type	Length	Value	Scope
Modulo capability	TBD	1	0: no modulo support 1: modulo support	REG-REQ REG-RSP
~~~~~~~~~~~~~~~~~~~~~~

yyy.y. Modulo mode support

This field indicates the SS operation mode. A SS uses this field in SBC-REQ in indicate its modulo operation mode. The BS uses this field in SBC-RSP to confirm the SS mode.

Name	Type	Length	Value	Scope
Modulo mode	TBD	1	0: no modulo mode 1: modulo mode	SBC-REQ/RSP

yyy.z. MU-MIMO feature support

This TLV indicates the MU-MIMO features supported by the BS

Name	Type	Length	Value	Scope
MU-MIMO feature	TBD	1	Bit #0: Linear Precoding Bit #1: Modulo support Bit #2-7: Reserved	REG-REQ REG-RSP

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References

[1] B. M. Hochwald, C. B. Peel, and A. L. Swindlehurst, “A vector-perturbation technique for near-capacity multiantenna multiuser communication—part II: perturbation,” *IEEE Trans. on Commun.*, vol. 53, no. 3, pp. 537-544, March 2005

[2] A. Lenstra, H. Lenstra and L. Lovasz, “Factoring Polynomials with Rational Coefficients”, *Math Ann.*, Vol. 261, pp. 515-534, 1982.

[3] C. B. Peel, B. M. Hochwald, and A. L. Swindlehurst, “A vector-perturbation technique for near-capacity multiantenna multiuser communication—part I: channel inversion and regularization,” *IEEE Trans. on Commun.*, vol. 53, no. 1, pp. 195-202, Jan. 2005

[4] C. Windpassinger, R. F. H. Fischer, and J. B. Huber, “Lattice-reduction-aided broadcast precoding,” *IEEE Trans. on Commun.*, vol. 52, no. 12, pp. 2057-2060, Dec. 2005

Appendix: Detailed Description of Vector Perturbation Non-linear Precoding

A MU-MIMO system employing n_T transmit antennas and K users with $n_R = \sum_{j=1}^{K} n_{R_j}$ receive antennas can be expressed in matrix notation as

(1) $$y = Hx + n,$$

where y is the received symbol vector, H the $n_R \times n_T$ channel matrix, x the transmitted symbols and n the noise vector of variance σ_n^2. The power constraint shall be given as $\|x\|^2 = 1$. Note that y contains the received signals of a multiple of users with one or more antennas each. Let u be the symbols prior to
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precoding, to be transmitted. To overcome the changes made by the channel matrix H, the vector is precoded by means of the Moore-Penrose pseudoinverse $\mathrm{H}^{+} = \mathrm{H}^{H}\left(\mathrm{HH}^{H}\right)^{-1}$ to

(2) $$s = H^{+}u,$$

using the zero-forcing (ZF) criterion. Prior to transmission the precoded signal s has to be scaled to fulfil the power restriction mentioned above, such that

(3) $$\mathrm{x} = \frac{s}{\sqrt{\gamma}},$$

where $\gamma = \| s \|^{2}$ [3]. In this proposal, γ shall be known at the receiver side. A large normalisation constant γ causes noise amplification at the receiver side. This is due to the fact that the receive symbol vector $\mathrm{y} = \sqrt{\gamma}\left(Hx + n\right)$ is impaired by a scaled Gaussian noise vector with variance $\sqrt{\gamma}\,\sigma_{n}^{2}$. The idea of vector perturbation is derived from TH precoding (THP) and allows each element of u to be perturbed by a complex integer. The perturbed data vector is then [1]

(4) $$\tilde{\mathrm{u}} = u + \tau l,$$

where τ is a positive real number and l is a complex integer vector in the dimensions of u. The scalar τ is chosen large enough so that the receivers may apply the modulo function

(5) $$\hat{u} = f_{\tau}(\mathrm{y}) = y - \left\lfloor \frac{\mathrm{y} + \tau / 2}{\tau} \right\rfloor \tau$$

to obtain the data vector sent, where the operation $\lfloor \cdot \rfloor$ rounds towards the nearest integer closest to zero. Note that $\hat{u}$ is not quantised and affected by additive noise. The block diagram of Vector Perturbation precoding can be seen in **Error! Reference source not found.**.

An obvious choice of τ and l that minimises $\gamma = \| s \|^{2}$ is

(6) $$l = argmin_{l'} \| H^{+}(u + \tau l') \|^{2}.$$

As already mentioned is this an integer-lattice least-squares problem in the dimensions of u, for which there exists a large number of algorithms, cf. references contained within [1].

The addition of the perturbation vector in (4) is in fact a shift of the transmit symbol to an implicitly extended constellation. The function f_{τ} (5) at the receiver side removes the effect of the symbol shift that has been done at the transmitter side; f_{τ} is applied element-wise separately to the real and imaginary part of the received vector y. The constellation shift parameter τ was initially given as [1]

(7) $$\tau = 2\left(| c |_{\max} + \Delta / 2\right)$$

in the case of M-QAM constellations, where $|\mathrm{c}|_{\max}$ is the absolute value of the real or imaginary part of the constellation symbol(s) with greatest magnitude and Δ is the smallest distance between two constellation symbols.

Figure 3 illustrates the modulo operation at the receiver side for a 16-QAM constellation. The received symbol, marked with an ‘x’, is shifted from the extended constellation (unfilled points) back to the original constellation (filled points), in which the symbol detection stage will be done. As one can see, the average number of neighbouring points will increase, which has an impact on the error protection of the outer symbols, since they will have a full number of neighbours now. The shift parameter τ as the distance between the constellation centres can lower this impact if it is chosen to be greater than defined in (7).

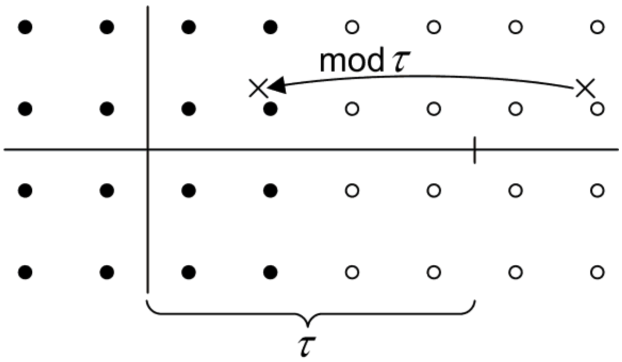

Figure 3: Modulo-τ operation at the receiver. Filled points: original 16-QAM constellation, unfilled points: extended constellation