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| Re: | In response to the Call for Contribution on Project 802.16m System Description Document (SDD) issued on 2008-03-20 (IEEE 802.16m-08/061r1)<br><br>Topic covered : Downlink MIMO schemes | |
| Abstract | Introduce the basis of non-linear multiuser-MIMO scheme 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 Call for Contribution on Project 802.16m System Description Document (SDD) issued on 2008-03-20 (http://www.ieee802.org/16/tgm/docs/80216m-08_016r1.doc) to propose a consideration of downlink MIMO schemes, especially, Multiuser-MIMO (MU-MIMO) schemes based on nonlinear processing.

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 MU-MIMO transmission, if multiple users are served.

We have already submitted documents numbered IEEE802.16m-08/205r2 and IEEE802.16m-08/58r1, describing the performance efficiency of the MU-MIMO schemes based on nonlinear processing. However, these results in the previous documents were not evaluated in practical systems. Therefore, we propose it again and provide a performance results based on the IEEE802.16e system.

## Description of Multiuser Tomlinson Harashima Precoding (THP)

Channel Inversion (CI) precoding overcomes the changes made by the channel during the transmission by applying the Moore-Penrose pseudo inverse 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 normalize the transmit power according to the restrictions of the base station. In order to solve the problem, the multiuser THP [2] uses modulo operation in order to reduce the transmit power, in combination with the successive cancellation at the transmitter. The block diagram of multiuser THP is shown in Figure 1.

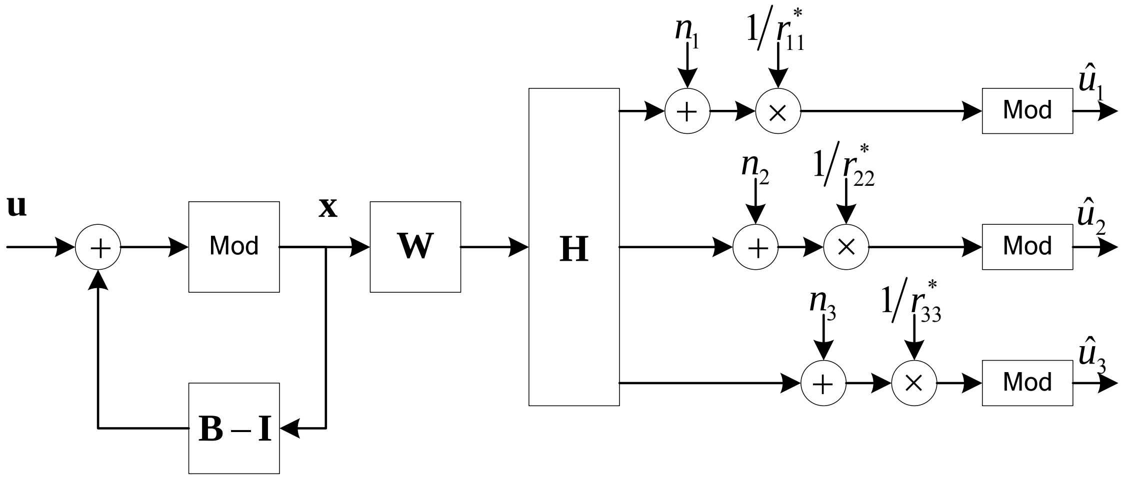


Figure 1: Block diagram of multiuser THP

In multiuser THP, a channel matrix can be decomposed as

$$\mathbf{H} = \mathbf{R}^H \mathbf{Q}^H \tag{1}$$

where **Q** is a unitary matrix and **R** is a upper triangular. We can then define the feedback matrix **B**, with ones on the diagonal, as

$$\mathbf{B} = \mathbf{G}\mathbf{R}^H \tag{2}$$

where the scaling matrix $\mathbf{G} = \mathrm{diag}\left(\left(\mathrm{r}_{11}^*\right)^{-1}, \left(\mathrm{r}_{22}^*\right)^{-1}, \cdots, \left(\mathrm{r}_{\mathrm{KK}}^*\right)^{-1}\right)$. Because of the triangular structure of the feedback matrix **B**, the symbols $x_k$, are successively generated from the data symbols $u_k \in \mathbf{A} = \left\{a_I + ja_Q \mid a_I, a_Q \in \pm1, \pm3, \ldots, \left(\sqrt{M} - 1\right)\right\}$

$$x_k = u_k - \sum_{l=1}^{k-1} b_{kl} x_l, k = 1, \ldots, K \tag{3}$$

Since this strategy would increase transmit power significantly, the modulo operation reduces the transmit symbols into the boundary region of **A**. Mathematically, integer multiples of $2\sqrt{M}$ are added to the real and imaginary part of $x_k$. Now, the channel symbols are given as

$$x_k = u_k + p_k - \sum_{l=1}^{k-1} b_{kl} x_l \tag{4}$$

where $p_k \in \left\{2\sqrt{M} \cdot \left(p_I + jp_Q\right) \mid p_I, p_Q \in \mathbf{Z}\right\}$. In other words, instead of feeding the data symbols $u_k$ into the linear pre-equalization, the effective data symbols $v_k = u_k + p_k$ are passed into $\mathbf{B}^{-1}$, which is implemented by the feedback structure. Note that this choice is unique and done implicitly by the modulo operation.

The output of the modulo operator is input to the feed forward matrix **W** that can be defined as

$$\mathbf{W} = \mathbf{Q}. \tag{5}$$

It is worth noting that the signal **x** is in the boundary region of **A** and the feed forward matrix is unitary so that there is no power penalty in multiuser THP.

The received signal denoted by $y$, can be written as

$$\begin{aligned}\mathbf{y} &= \mathbf{H}\frac{1}{\sqrt{\gamma}}\mathbf{W}\mathbf{x}+\mathbf{n} = \frac{1}{\sqrt{\gamma}}\mathbf{H}\mathbf{Q}\mathbf{B}^{-1}\mathbf{v}+\mathbf{n} \\ &= \frac{1}{\sqrt{\gamma}}\mathbf{R}^{H}\left(\mathbf{G}\mathbf{R}^{H}\right)^{-1}\mathbf{v}+\mathbf{n} \\ &= \frac{1}{\sqrt{\gamma}}\mathbf{G}^{-1}\mathbf{v}+\mathbf{n} \\ &= \frac{1}{\sqrt{\gamma}}\mathbf{G}^{-1}\left(\mathbf{u}+\mathbf{p}\right)+\mathbf{n}\end{aligned} \tag{6}$$

where $\gamma = \|\mathbf{W}\mathbf{x}\|^2$, imposing a transmit power constraint of 1 in (6).

Since the $\boldsymbol{G}^{-1}$ is a diagonal, the interference at the users are eliminated . After the scaling operation of $\sqrt{\gamma}\mathbf{G}$, the received signal is fed into the modulo operation at the receiver and the original sequence **u** is recovered, because the modulo reduction is a unique operation. The example of the modulo reduction at the receiver is shown in Figure 2, where an example receive vector "x" is mapped from the extended constellation back into the borders of the original constellation.

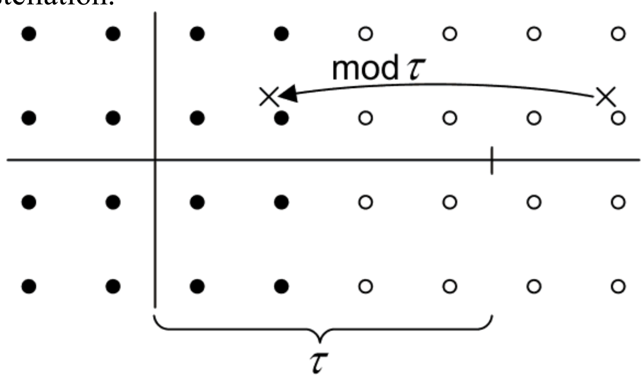


Figure 2 Modulo-τ operation at the receiver. Filled points: original 16-QAM constellation, unfilled points: extended constellation

## Performance of the multiuser THP in IEEE802.16e system

In this section, we demonstrate the performance achieved by the proposed non-linear technique Tomlinson-Harashima Precoding (THP) compared to Channel Inversion (CI) precoding. Here, we consider a multi-user downlink with a Gaussian MIMO channel. We assume a base station having three transmit antennas, and three users equipped with one receive antenna each, respectively. We further assume perfect channel knowledge at the transmitter. The system is based on the IEEE802.16e system with AMC2x3 subcarrier allocation. The FFT size is 1024 and the channel model is SCM with urban micro cell environment. The MCS is 16QAM with convolutional coding of R=3/4. In each frame, spatial streams are being transmitted to the users, one per user. The SNR is defined as $SNR = \gamma/\gamma_n$ where $\gamma_n$ is a noise variance at the receiver.

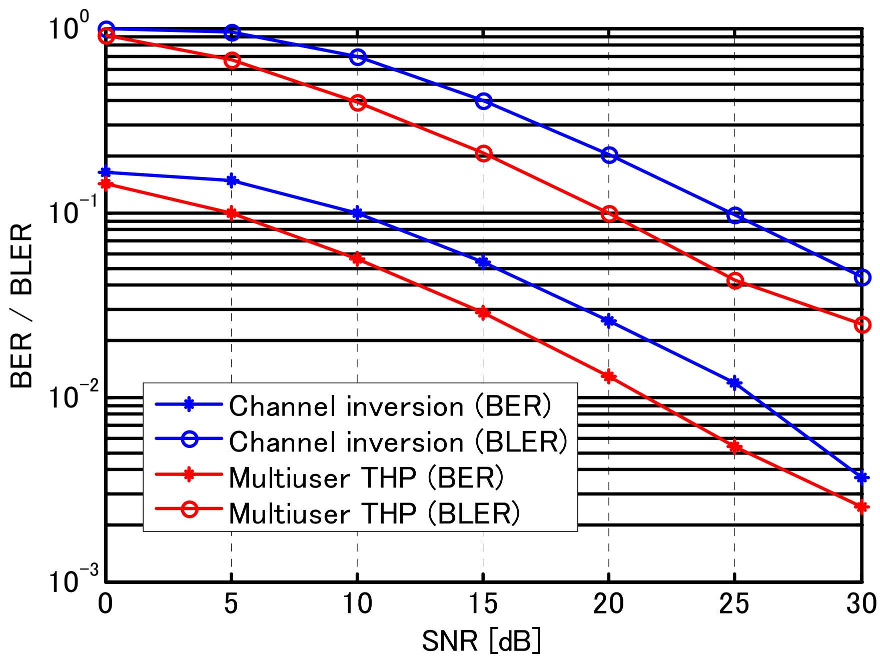


Figure 3: Comparison of THP and Channel Inverse Precoding

Figure 3 shows the average performance of BER and Block Error Rate (BLER). The gain in terms of BLER between Channel Inversion Precoding and multiuser THP is evident, as we can observe a performance gap of approx. 5 dB at the 0.1% BLER line, which has shown clearly that the proposed nonlinear THP precoding achieves significant gain over linear precoding.

## Conclusion

Nonlinear downlink MU-MIMO schemes based on multiuser THP was evaluated in a IEEE802.16e system and showed performance improvement over the linear MU-MIMO scheme. The key processing for nonlinear processing is the modulo operation for both the base stations and the user terminals.

We therefore proposed to implement the downlink MU-MIMO based on nonlinear processing such as multiuser THP and multiuser vector perturbation. The detail of the multiuser vector perturbation can be found on our past document (IEEE802.16m-08/058r1). For both schemes, the SSs only needs to implement a modulo function, which can remove the constellation shift effect of non-linear precoding. It is worth noting that the both schemes does not much affect the current implementation of the SSs. 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** ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

## xx. MIMO scheme

## x.x.x MU-MIMO

*[Insert the following subclause]*
~~~~~~~~~~~~~~~~~~~~~~~

### x.x.x.y Linear processing

### x.x.x.z Nonlinear processing

Nonlinear processing below needs the modulo operation for both the transmitters and receivers.

### x.x.x.z.x Multiuser Tomlinson-Harashima Precoding (THP)

The multiuser THP uses the modulo operation in combination with the successive cancellation at the transmitter.

### x.x.x.z.y Multiuser Vector Perturbation (VP)

*[Author's note: The detail description of the multiuser VP can be found in our contribution numbered IEEE802.16m-08/058r1]*

### x.x.x.z.z Pilot structure for nonlinear MU-MIMO

*[Author's note: The detail description of the pilot structure can be found in our contribution numbered IEEE802.16m-08/205r2]*

## 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<br>1: modulo support | REG-REQ<br>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<br>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<br>Bit #1: VP<br>Bit #2: THP<br>Bit #3-7: Reserved | REG-REQ<br>REG-RSP |

While the TLV indicates the MU-MIMO features supported by the BS is THP precoding, the pilot specified in subclause x.x.x.y.z shall be adopted.

**~~~~~~~~~~~~~~~~~~~ Text Input end ~~~~~~~~~~~~~~~~~~~~~~~~~~~~**

## 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] C. Windpassinger, R. F. H. Fischer, T. Vencel, and J. B. Huber, "Precoding in multiantenna and multiuser communications, " *IEEE Trans. on Wireless Commun.*, vol., 3, no. 4, July 2004.