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Re:	IEEE 802.16m-08/024, Call for Comments and Contributions on Project 802.16m System Description Document (SDD) on topic Hybrid ARQ (PHY aspects)
Abstract	This contribution proposes two Hybrid ARQ schemes: Hybrid ARQ scheme for closed-loop MIMO systems and a hybrid ARQ scheme with LLR aware QAM symbol mapping.
Purpose	Adoption of the proposed text into SDD
Notice	
Release	
Patent Policy	

Hybrid ARQ Schemes for IEEE 802.16m

1. Hybrid ARQ for a Closed-Loop MIMO System

Introduction and Background

In the conventional closed-loop MIMO system, e.g., the codebook-based approach in IEEE 802.16e specification, the typical underlying assumption is that a pre-coding matrix is not updated even when the multiple receptions of the same signal are available under the HARQ process. In order to fully utilize multiple receptions of MIMO signals, however, a pre-coding matrix is updated for every retransmission by taking a symbol level combining gain obtained with the previous receptions into account. Towards this end, there must be an appropriate criterion of the pre-coding matrix selection so as to minimize the error probability of retransmission. Furthermore, ACK or NACK signaling must be properly synchronized with the feedback of pre-coding matrix index. In this proposal, therefore, we suggest that a feedback structure for the closed-loop MIMO processing must be jointly considered in cooperation with the hybrid ARQ operation in IEEE 802.16m.

System Model

Let use consider a MIMO system with N_T transmit antennas and N_R receive antennas (In general, $N_R \geq N_T$). A signal vector $\mathbf{s}$ is first coded by an $N_T \times N_T$ pre-coding matrix, each of which is selected from a predefined set of the pre-coding matrices, S, and then, transmitted over the given $N_R \times N_T$ MIMO channel $\mathbf{H}$. Then, the received signal is represented as follows:

$$\mathbf{y} = \mathbf{HFs} + \mathbf{w} = \tilde{\mathbf{H}}\mathbf{s} + \mathbf{w} \tag{1}$$

where $\tilde{\mathbf{H}} = \mathbf{HF}$ and $\mathbf{w}$ is the thermal noise vector. Denoting the channel matrix and pre-coding matrix at the l-th transmission by $\mathbf{H}_l$ and $\mathbf{F}_l$, respectively, the above relationship for the lth transmission can be written as follows:

$$\mathbf{y}_l = \mathbf{H}_l\mathbf{F}_l\mathbf{s} + \mathbf{w}_l = \tilde{\mathbf{H}}_l\mathbf{s} + \mathbf{w}_l . \tag{2}$$

where $\tilde{\mathbf{H}}_l = \mathbf{H}_l\mathbf{F}_l$. If the channel coefficients remain constant during every transmission attempt for single block, i.e., $\mathbf{H}_l = \mathbf{H}_k$, for all l and k, the corresponding channel is referred to a Long-Term-Static (LTS) channel. Otherwise, i.e., the channel changes independently at every transmission, then it is referred to as a Short-Term-Static (STS) channel. After L receptions and concatenation, the relationship between transmitted and received signal is given by

$$\mathbf{y} = \begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \\ \vdots \\ \mathbf{y}_L \end{bmatrix} = \begin{bmatrix} \mathbf{H}_1\mathbf{F}_1 \\ \mathbf{H}_2\mathbf{F}_2 \\ \vdots \\ \mathbf{H}_L\mathbf{F}_L \end{bmatrix} \mathbf{s} + \begin{bmatrix} \mathbf{w}_1 \\ \mathbf{w}_2 \\ \vdots \\ \mathbf{w}_L \end{bmatrix} = \mathbf{H}_{CONC}\mathbf{s} + \mathbf{w} . \tag{3}$$

where $\mathbf{H}_{CONC}$ represents an overall diversity matrix concatenated from a sequence of the selected pre-code matrices $\mathbf{F}_l$ for the given channel conditions $\mathbf{H}_l$, $l = 1, 2, \cdots, L$. Meanwhile, the transmitted signal vector $\mathbf{s}$ and thermal noise vector $\mathbf{w}_l$, the followings are assumed:

$$\mathbf{R}_{\mathbf{s}} = \sigma_{\mathbf{s}}^2 \mathbf{I}_{N_T} \tag{4}$$

and

$$\mathbf{R}_{\mathbf{w}_l} = \sigma_{\mathbf{w}_l}^2 \mathbf{I}_{N_R} . \tag{5}$$

Subsequently, the average SNR is defined as $\overline{\gamma} = \sigma_s^2 / \sigma_w^2$. Let $\mathbf{G}_l$ be an equalizing matrix in the receiver for the L-th transmission. For example, detection for the initial transmission is given as follows:

$$\hat{\mathbf{s}} = \mathbf{G}_1 \mathbf{H}_1 \mathbf{F}_1 \mathbf{s} + \mathbf{G}_1 \mathbf{w}_1$$

where $\mathbf{F}_1$ and $\mathbf{G}_1$ are jointly determined by the following MMSE criterion:

$$\left(\mathbf{F}_1^{MMSE}, \mathbf{G}_1^{MMSE} \right) = \underset{(\mathbf{F}_1,\, \mathbf{G}_1)}{\arg\min}\, E\left\{ \left\| \hat{\mathbf{s}} - \mathbf{s} \right\|^2 \right\}$$

Furthermore, detection for the L-th transmission is given as follows:

$$\hat{\mathbf{s}} = \mathbf{G}_L \mathbf{r} = \mathbf{G}_L \begin{bmatrix} \mathbf{r}_1 \\ \mathbf{r}_2 \\ \vdots \\ \mathbf{r}_L \end{bmatrix} = \mathbf{G}_L \begin{bmatrix} \mathbf{H}_1 \mathbf{F}_1 \\ \vdots \\ \mathbf{H}_{L-1} \mathbf{F}_{L-1} \\ \mathbf{H}_L \mathbf{F}_L \end{bmatrix} \mathbf{s} + \mathbf{G}_L \begin{bmatrix} \mathbf{w}_1 \\ \vdots \\ \mathbf{w}_{L-1} \\ \mathbf{w}_L \end{bmatrix} \tag{5}$$

where $\mathbf{F}_l$ and $\mathbf{G}_l$ are jointly determined by the following MMSE criterion:

$$\left(\mathbf{F}_l^{MMSE}, \mathbf{G}_l^{MMSE} \right) = \underset{(\mathbf{F}_l,\, \mathbf{G}_l)}{\arg\min}\, E\left\{ \left\| \hat{\mathbf{s}} - \mathbf{s} \right\|^2 \right\} \tag{6}$$

For the MMSE criterion, note that the linear equalizing matrix $\mathbf{G}_L$ for the given $(\mathbf{F}_1, \mathbf{F}_2, \cdots, \mathbf{F}_L)$ is given as follows:

$$\mathbf{G}_L = \left(\mathbf{H}_{CONC}^H \mathbf{H}_{CONC} + \mathbf{I}_{N_T} / \overline{\gamma} \right)^{-1} \mathbf{H}_{CONC}^H . \tag{7}$$

For the L-th transmission, then, the signal is recovered as $\hat{\mathbf{s}} = \mathbf{G}_L \mathbf{y}$. This particular approach is referred to as a progressive linear pre-coding scheme in [1]. The overall system structure is illustrated in Fig. 1.

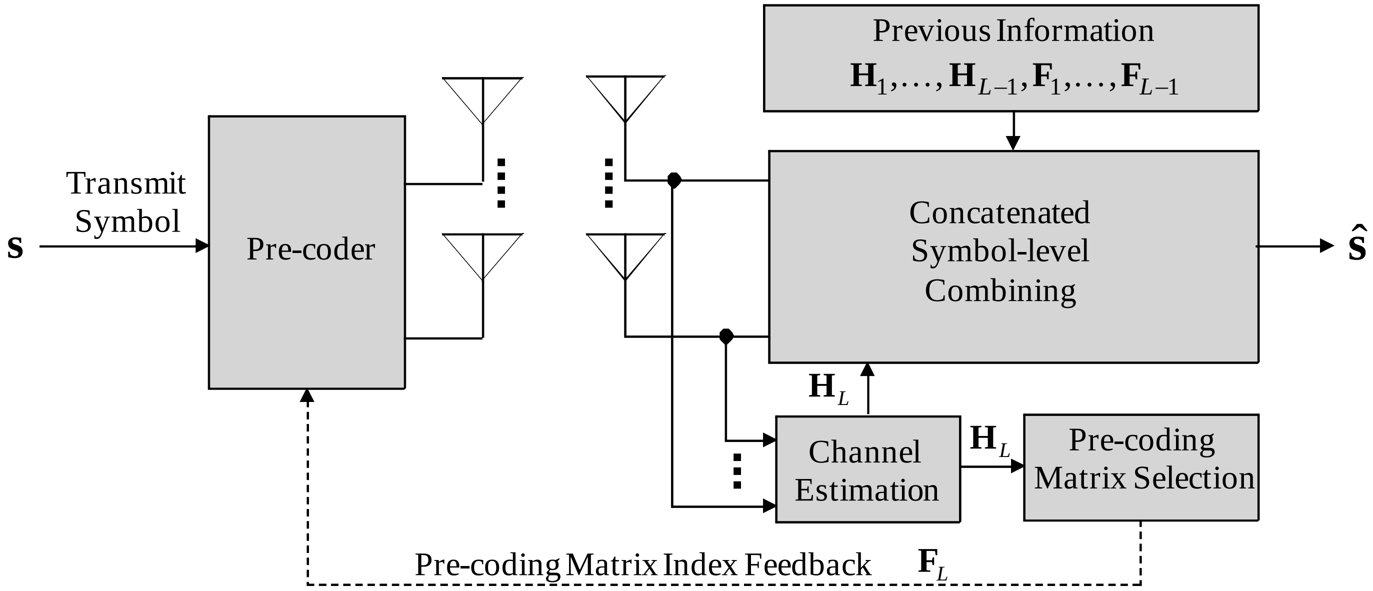


Figure 1. Retransmission System Structure

Pre-coding Matrix Selection: Example

For the L-th transmission, the pre-coding selection problem is to determine a pre-coding matrix $\mathbf{F}_L$ out of the pre-defined set $\mathbf{S}$, that maximizes the given cost function under the condition that the pre-coding matrices and channel matrices for the previous transmissions. For the given channel conditions for all transmissions, the cost function depends on the previous pre-coding matrix as well as the pre-coding matrix for the current transmission. As an example, we consider an effective SNR (ESNR) as the corresponding cost function in the subsequent discussion. Note that ESNR is given by the post-detection SNR's (PD-SNR) of the linear equalizer for all different streams. For the given receiver $\mathbf{G}$ and the channel $\tilde{\mathbf{H}} = \mathbf{HF}$, PD-SNR for i th symbol is expressed as follows:

$$\gamma_i = \frac{\left|\mathbf{g}_i \tilde{\mathbf{h}}_i\right|^2 \sigma_{\mathbf{s}}^2}{\sum_{j \neq i}^{N_T} \left|\mathbf{g}_j \tilde{\mathbf{h}}_i\right|^2 \sigma_{\mathbf{s}}^2 + \left\|\mathbf{g}_i\right\|^2 \sigma_{\mathbf{w}}^2} \tag{8}$$

where $\mathbf{g}_i$ and $\tilde{\mathbf{h}}_j$ are i th row and j th column of $\mathbf{G}$ and $\tilde{\mathbf{H}} = \mathbf{HF}$, respectively. In fact, PD-SNR vector is a function of $\tilde{\mathbf{H}}$ only, since the equalizing matrix $\mathbf{G}$ is calculated for the given $\tilde{\mathbf{H}}$. Given the PD-SNRs for all the different streams, $(\gamma_1, \gamma_2, \cdots, \gamma_{N_T})$, there are many different methods of ESNR mapping[2-7]. In the current discussion, we consider a Shannon capacity-based mapping method, which is given as follows:

$$\gamma_{eff} = 2^{\frac{1}{N_T}\sum_{i=1}^{N_T} \log_2\left(1+\gamma_i\left(\mathbf{H}_{CONC}\right)\right)} - 1 \tag{9}$$

$\mathbf{H}_{CONC}$ is constructed for all possible pre-coding matrices $\mathbf{F} \in S$ and then, a pre-coding matrix which maximizes the corresponding ESNR is selected. Fig. 2 summarizes the overall steps to select the pre-coding matrix for the L-th transmission.

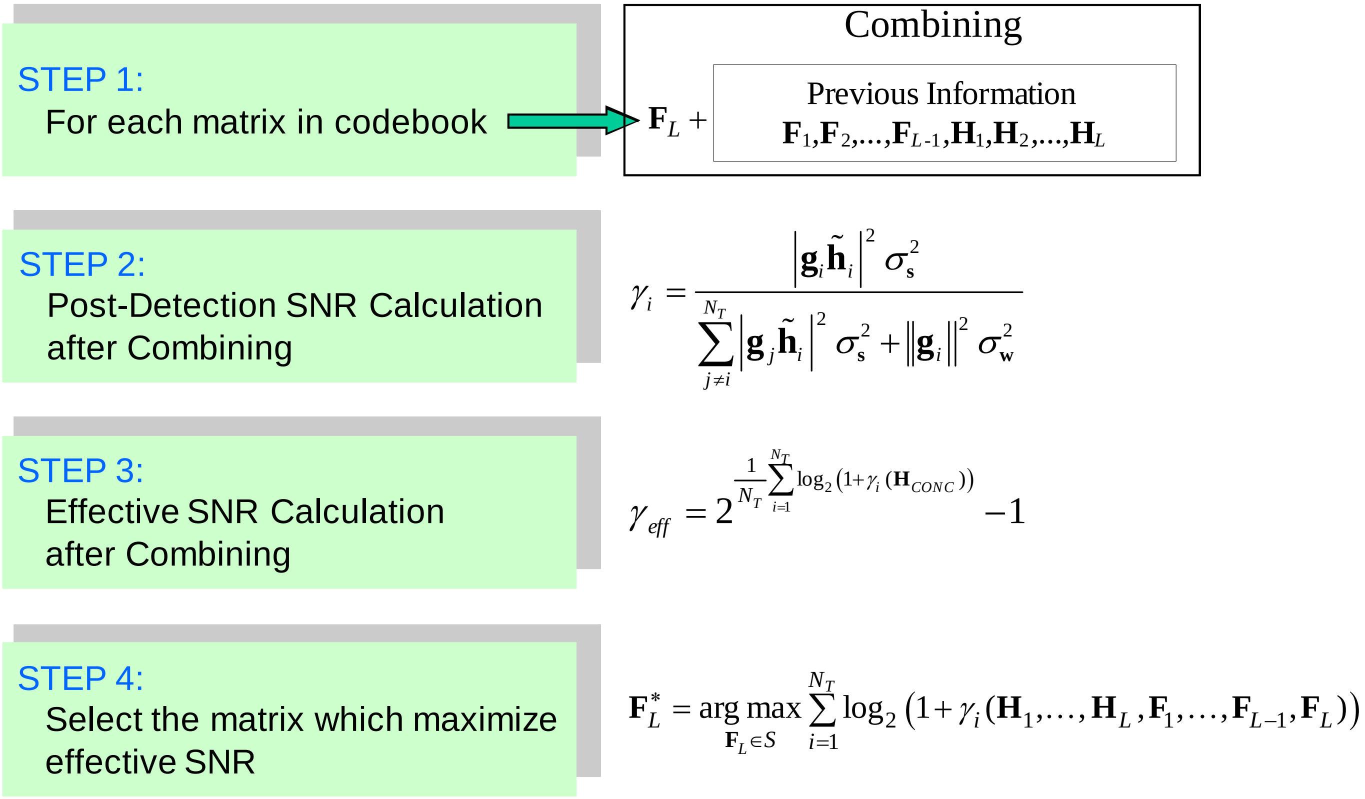


Figure 2. Effective SNR-based Pre-coding Matrix Selection

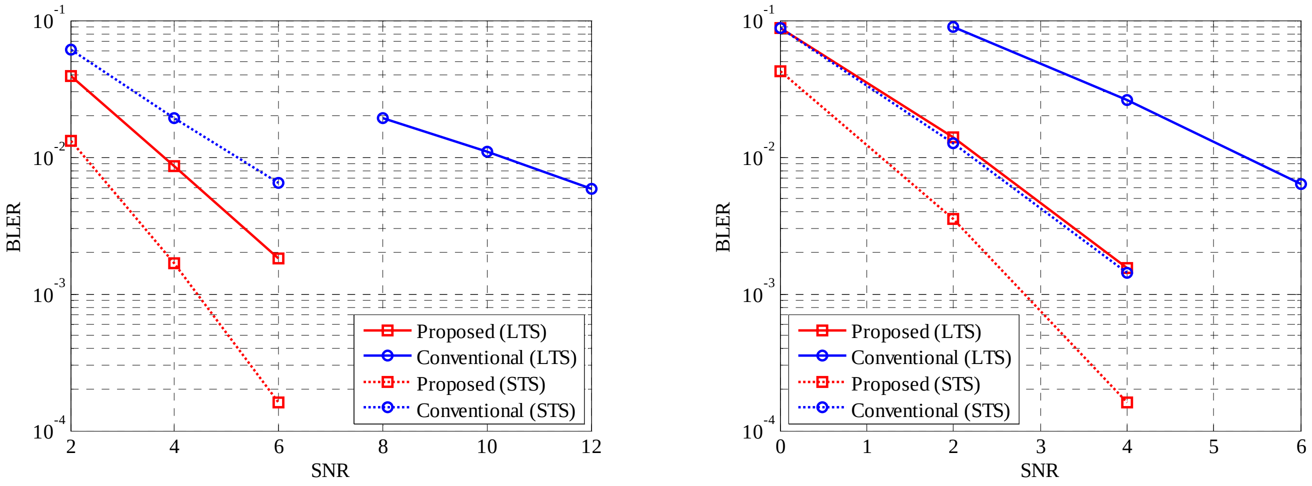
Simulation Results

In the current simulation, the numbers of transmit and receive antennas are given by 4 and 2, respectively (N_T = 4 and N_R = 2). QPSK-modulated signals are linearly pre-coded by using the codebook specified by IEEE 802.16e standard and transmitted over 12 continuous subcarriers of OFDM system. We consider both correlated and uncorrelated MIMO channels. For the correlated case, we consider one associated with the urban macro-cell environment. The simulation parameters are summarized in Table 1.

Fig. 3 shows a BLER performance of the 2nd transmission under the correlated and uncorrelated environments. For the spatially correlated environment (Fig. 3(a)), it is shown that the progressive linear pre-coding scheme provides an approximately 6dB gain over the conventional retransmission scheme under the long-term-static channel. Under the short-term-static channel, we still find an almost 3dB gain over the conventional one, which implies that a time diversity gain can be maintained over the STS channel for the progressive linear pre-coding scheme. For the spatially uncorrelated environment (Fig. 3(b)), the overall gain is relative reduced as compared that for the spatially correlated environment, but the progressive linear pre-coding scheme is still useful for both STS and LTS channels.

Table 1. Simulation Parameters

Parameters	Value
Channel	Short-Term-Static (STS) or Long-Term-Static (LTS)
Codebook	IEEE 802.16e 3bit codebook
Antenna	4 Tx & 2 Rx antennas
Spatial Correlation	Urban macro in 16m EMD
Subcarrier Allocation	Localized mode (14 subcarriers)



(a) Spatially Correlated Channel

(b) Spatially Uncorrelated Channel

Figure 3. Block Error Rate for 2nd Transmission

Conclusion

It has been shown that a progressive pre-coding scheme can be useful for a hybrid ARQ process in the closed-loop MIMO system, even with an existing set of the pre-coding matrix in IEEE 802.16m. We suggest that a signaling structure in IEEE 802.16m must be properly designed so as to incorporate this particular concept into the practice. Furthermore, a new set of pre-coding matrix can be derived that optimize the overall performance subject to the progressive pre-coding scheme. Meanwhile, a similar concept can be extended to the multi-user MIMO processing.

2. **LLR Aware QAM Symbol Mapping Scheme**

QAM (quadrature amplitude modulation) makes it possible to transmit data at high rate by mapping multiple data bits to a single symbol. Within a symbol, however, the reliability of a bit varies depending on its location within the symbol [8]. Figure 4 shows an example of 16 QAM constellation and symbol mapping, where bits i_1 and q_1 have higher reliability than bits i_2 and q_2.

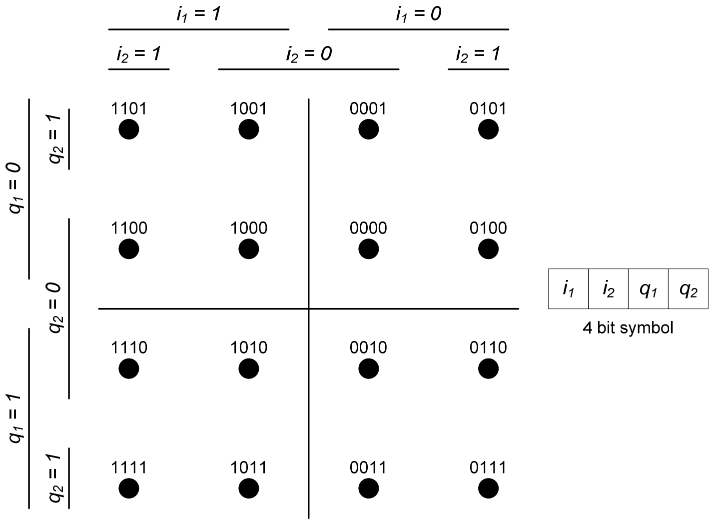


Figure 4. 16 QAM Constellation and the bit reliability

Systematic channel coders refer to a family of channel coders for which the input sequence (the information bits) also appears at the output (the information bit block) in addition to the redundancy bits (redundancy bit block) added by the channel coder. Conventionally, the information bits and the redundancy bits are not distinguished when the coded bits are mapped to QAM symbols.

However, when the coded bits are mapped to QAM symbols, by taking advantage of the fact that the reliability of each bit within a symbol is different, we can give the information bits and the redundancy bits different average reliability to improve the performance. For example, the information block of the coded bits are mapped to the more reliable bits of the QAM symbol, and the redundancy block of the coded bits are mapped to the less reliable bits of the QAM symbol. Figure 5 illustrates schematics of the proposed QAM symbol mapping scheme.

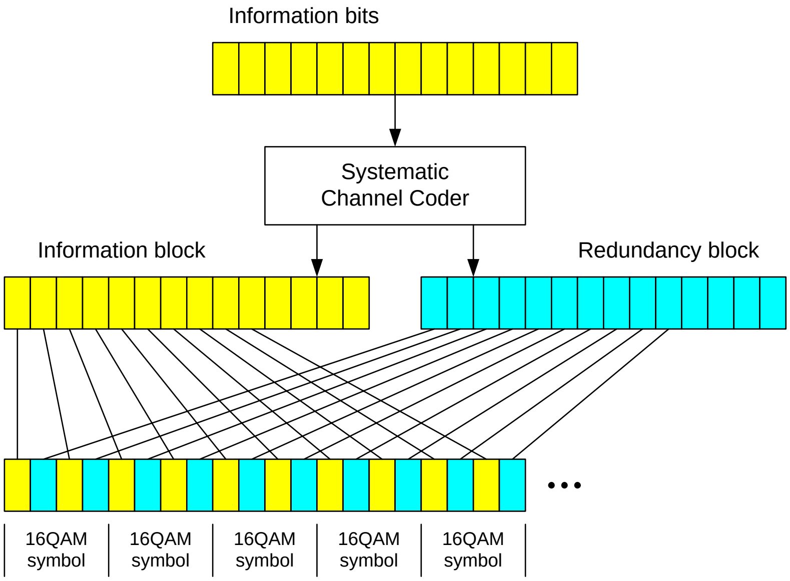


Figure 5. QAM symbol mapping of the coded bits. (16 QAM)

Hybrid ARQ

The extension of the proposed scheme to Hybrid ARQ is straightforward. Instead of retransmitting the identical QAM symbol sequence as the first transmission, a different QAM symbol mapping is used for the second transmission. For example, for the second transmission, the redundancy block of the coded bits are mapped to the more reliable bits of the QAM symbol, and the information block is mapped to the less reliable bits of the QAM symbol. Figure 6 illustrates the QAM symbol mapping scheme for the second transmission of Hybrid ARQ.

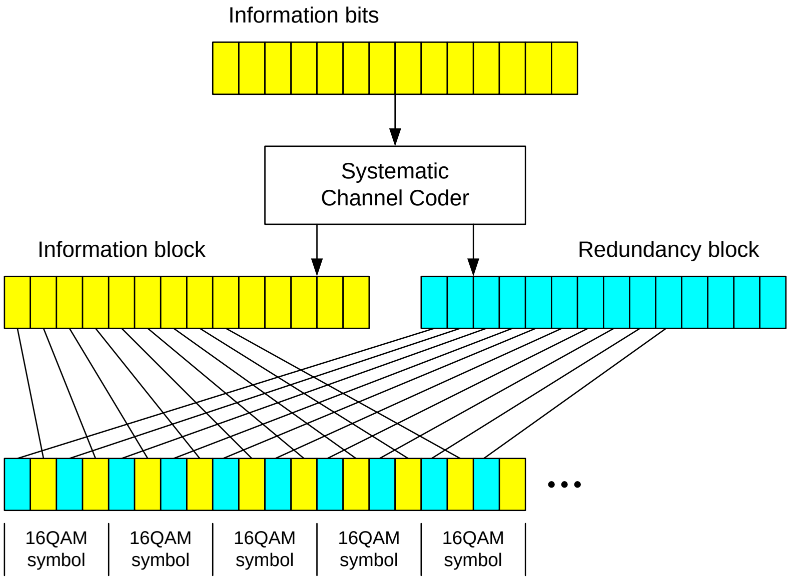


Figure 6. QAM symbol mapping scheme for the second transmission of hybrid ARQ. (16 QAM)

Simulation Results

Figure 7 shows the coded BER performance comparing the conventional QAM symbol mapping scheme in IEEE 802.16e with the proposed QAM symbol mapping scheme. An independent identical fading channel was assumed and the CTC 1/2 was used as channel coding scheme. As shown in the figure, when the information block of the output of the CTC 1/2 is assigned to the QAM symbol bits with higher reliability, we have about 3dB gain compared to the conventional QAM symbol mapping scheme in the IEEE 802.16e, where the information block and the redundancy block have the same average bit reliability.

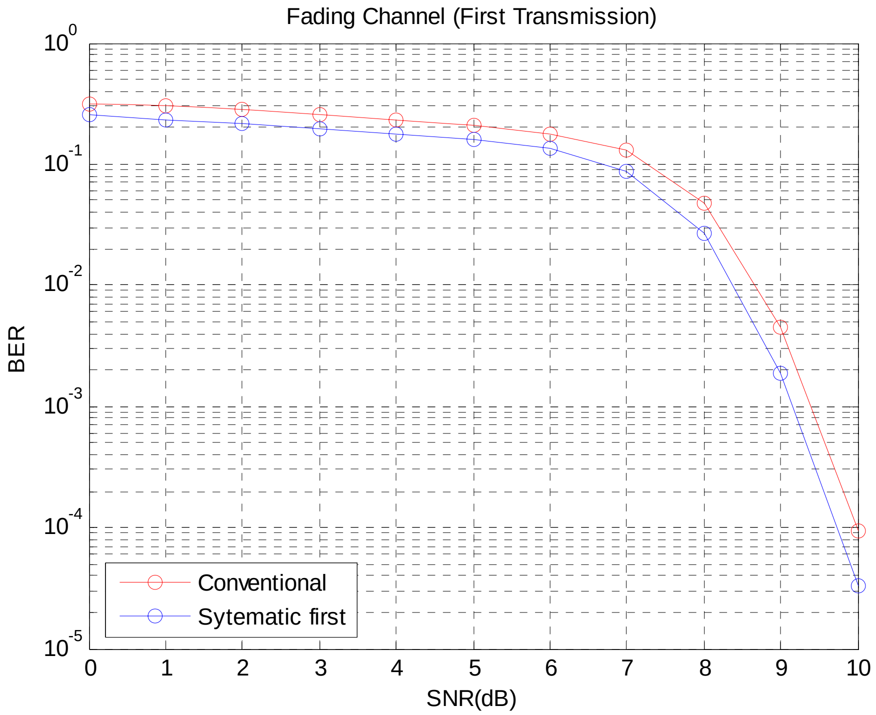


Figure 7. The coded BER performance comparing the conventional QAM symbol mapping scheme in IEEE 802.16e and the proposed QAM symbol mapping. (CTC 1/2, iid fading channel.)

Proposed Text for SDD

***Insert the following text into* SDD Section 11 – Physical Layer [5]**

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11.x Hybrid ARQ

11.x.y Hybrid ARQ for MIMO

In a codebook-based closed-loop MIMO system, a linear pre-coding matrix for retransmission can be selected by taking a symbol level combining gain with the previous reception into account. In this HARQ process, a NACK message and the corresponding pre-coding matrix index must be jointly signaled in the uplink control channel. Therefore, the message which is not received successfully in the previous transmission is retransmitted by using the pre-coding matrix that has been reported along with NACK. Furthermore, a new set of pre-coding matrix must be investigated to optimize the overall performance. Meanwhile, a similar concept can be extended to the multi-user MIMO processing.

11.x.z Chase Combining Hybrid ARQ Mode

QAM modulation maps multiple coded bits to a single symbol, where the reliability of each bit varies depending on its location within the QAM symbol. The difference of reliabilities of bits within a QAM symbol is taken into account in QAM modulation process of coded bits for the first and the subsequent transmissions of the hybrid ARQ in IEEE 802.16m. The QAM modulation process maps the information block of the coded bits to the bits of QAM symbol with high reliability for the first transmission. For the subsequent transmissions, mapping schemes different from that of the first transmission can be used to achieve improved hybrid ARQ performance. For example, the information block can be mapped to the bits with low reliability for the second transmission.

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References

[1] Haitong Sun, Jonathan H. Manton, and Zhi Ding, “Progressive Linear Precoder Optimization for MIMO Packet Retransmissions,” IEEE Journal on Selected Areas in Communications, vol. 24, no. 3, March 2006.

[2] “1xEV-DV Evaluation Methodology (V13),” 3GPP2 TSG – C.R 1002.

[3] “Considerations on the System-Performance evaluation of HSDPA using OFDM modulation,” Ericsson, 3GPP TSG_RAN WG1 #34, R1-030999, October, 2003.

[4] “System-Level evaluation of OFDM - further Considerations,” Ericsson, 3GPP TSG-RAN WG1 #35, R1-031303, November 17-21, 2003.

[5] “Reverse Link Hybrid ARQ: Link Error Prediction Methodology Based on Convex Metric,” Lucent Technologies, 3GPP2 TSG-C, C30-20030401-020, April, 2003.

[6] “Effective-SNR Mapping for Modeling Frame Error Rates in Multiple-state Channels,” Ericsson, 3GPP2 WG3, C30-20030429-010, April, 2003.

[7] “Draft IEEE 802.16m Evaluation Methodology,” IEEE 802.16m-07/037r2, December 17, 2007.

[8] C. Wengerter, A. G. E. Von Elbwart, E. Seidel, G. Velev, P. Schmitt, “Advanced hybrid ARQ Technique Employing a Signal Constellation Rearrangement,“ in Proceedings of VTC 2002 Fall, vol. 4, Sept. 2002, pp. 2002-2006.