Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**	
Title	**Enhanced MIMO Transmission Schemes for Cellular OFDMA Systems**	
Date Submitted	**2004-07-08**	
Source(s)	Chan-Byoung Chae, Wonil Roh, JeongTae Oh, Kyunbyoung Ko, Hongsil Jeong, Sung-Ryul Yun, Seungjoo Maeng, Panyuh Joo, Jaeho Jeon, Jaeyeol Kim, Soonyoung Yoon **Samsung Electronics Co., Ltd.** 416, Maetan-3, Yeongtong, Suwon, Gyeonggi, Korea 442-600	wonil.roh@samsung.com Voice: +82-31-279-3868
Re:	Contribution supporting TGe WG ballot #14b	
Abstract	Enhanced MIMO Transmission Schemes for Cellular OFDMA Systems	
Purpose	Adoption of proposed changes into P802.16e ~~Crossed-out indicates deleted text,~~ underlined blue indicates new text change to the Standard, and underlined green indicates newly added text from the original contribution	
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Enhanced MIMO Transmission Schemes for Cellular OFDMA Systems

Chan-Byoung Chae, Wonil Roh, JeongTae Oh, Kyunbyoung Ko, Hongsil Jeong, Sung-Ryul Yun, Seungjoo Maeng, Panyuh Joo, Jaeho Jeon, Jaeyeol Kim, Soonyoung Yoon
Samsung Electronics

1. Introduction

From a pure diversity standpoint, one can enhance the fading statistics of the received signal by virtue of the multiple replicas being affected by independent channels. By sending the same signal through parallel and independent channels, the effect of multipath fading can be greatly reduced, decreasing the outage probability and hence improving the reliability of the communication link. In other approach, referred to as spatial multiplexing, different information streams are transmitted on the parallel spatial channels associated with the transmit antennas. This could be seen as a very effective method to increase spectral efficiency. We are also considering a mixed-mode combining the advantages of both methods. The mixed mode approach can be seen as a good engineering compromise, where multipath fading is effectively combated by diversity while attaining a high spectral efficiency due to spatial multiplexing. ~~In addition, transmit antenna array (TxAA) scheme will be considered to increase the received SINR at SS.~~

STC enhancements with multiple antennas at BS and SS for optional FUSC and AMC zones for OFDMA PHY are provided in the current draft standard [1]. Pilots and data allocation methods are described and the transmission schemes for 2 and 4 antenna BS are also suggested. In this contribution we propose a new transmission scheme for 4 Tx which outperforms the existing one. In addition, an effort to remove the confusing matrices regarding closed-loop operation is made. ~~Lastly, the necessary changes in MAP IEs that should be made to reflect the proposal are proposed.~~

2. SBC-REQ/RSP Changes for MIMO Support

For OFDMA system, the current standard [1] lacks the mechanism for an SS to report its capability to a BS during initialization period, when SS basic capabilities are conveyed to BS on SBC-REQ and confirmed by BS on SBC-RSP. The necessary TLV definitions for the MIMO support are added as follows.

2.1. Specific Text Changes

[Add a new section 11.8.3.7.6 in page 687 of [1]]

11.8.3.7.6 OFDMA SS demodulator for MIMO support

This field indicates the MIMO capability supported by a WirelessMAN-OFDMA PHY SS for downlink reception. A bit value of 0 indicates "not supported" while 1 indicates "supported".

Type	Length	Value	Scope
155	1	Bit #0: 2x TD Bit #1: 4x TD Bit #2: 2x SM	SBC-REQ (see 6.3.2.3.23) SBC-RSP (see 6.3.2.3.24)

		Bit #3: 4x SM Bit #4: 2x SM, 2x TD ~~Bit #5: SVD capability~~ ~~Bit #6: Antenna weight calculation~~ Bit #5-7: Reserved; shall be set to zero	

[Add a new section 11.8.3.7.7 in page 687 of [1]]

11.8.3.7.7 OFDMA SS modulator for MIMO support

This field indicates the MIMO capability supported by a WirelessMAN-OFDMA PHY SS for uplink reception. A bit value of 0 indicates "not supported" while 1 indicates "supported".

Type	Length	Value	Scope
156	1	Bit #0: 2x TD Bit #1: 2x SM Bit #2-7: Reserved; shall be set to zero	SBC-REQ (see 6.3.2.3.23) SBC-RSP (see 6.3.2.3.24)

3. MIMO Transmission Schemes

For the downlink, a MIMO SS monitors the channel quality, selects and feedbacks to the BS an appropriate MIMO mode or multiple modes among diversity, spatial multiplexing~~, or TxAA~~ schemes. For the uplink, each MIMO SS operates in open-loop basis and selects the transmission scheme among diversity, multiplexing or collaborative multiplexing.

3.1. Transmission Schemes for 2 Tx

In order to confirm the performance gain over 1x1 SISO, a 2x2 spatial multiplexing scheme is simulated on band AMC mode in the OFDMA downlink. The results are shown in Figure 1, where the comparison can be made to see the SNR advantage of MIMO over SISO to achieve the same packet error rate. The simulation conditions are following:
Ped B 10 km/h; channel estimation with pilots (See Figure 207 in page 96 [1]); CTC and Max-log-MAP decoder used; For MIMO, MMSE nulling and MMSE ordering used; Normalization error due to channel variation considered.

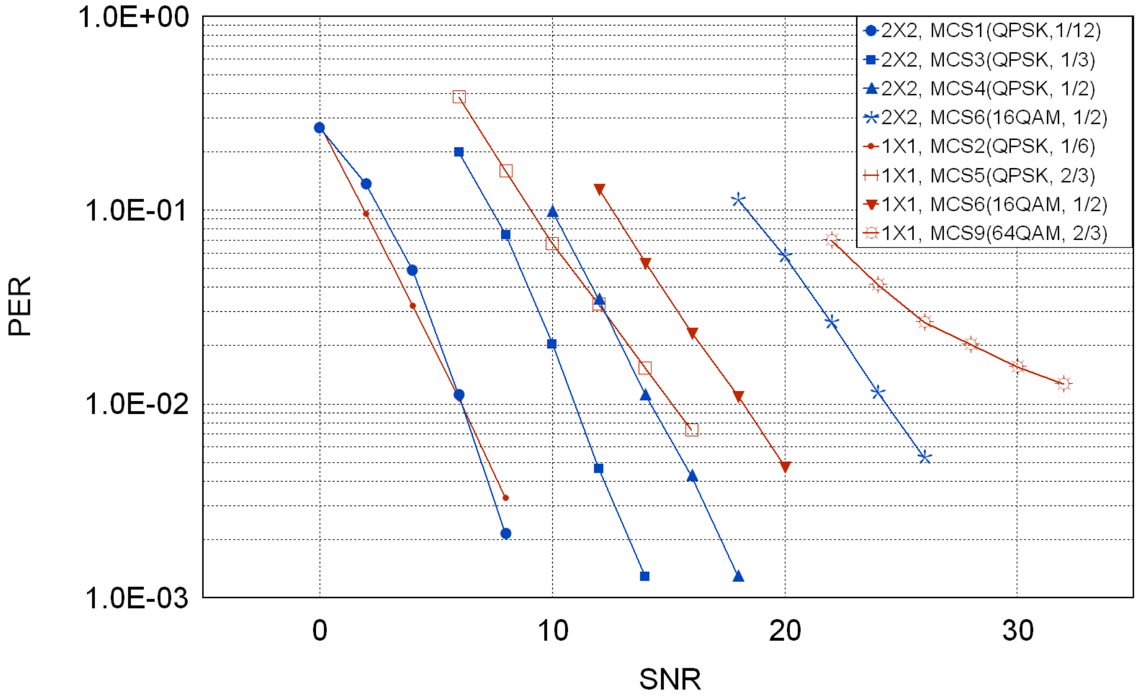


Figure 1 PER for SISO and MIMO in Ped B 10 km/h

3.1.1. Specific Text Changes

[Replace the section 8.4.8.3.3 with the following]

8.4.8.3.3 Transmission schemes for 2-antenna BS in DL

The following matrices define the transmission format with the row index indicating antenna number and column index indicating OFDMA symbol time. For both DL permutation zones with 2-antenna BS, one of the following ~~three~~ two transmission matrices shall be used:

Diversity mode : $A = \begin{bmatrix} S_i & -S_{i+1}^* \\ S_{i+1} & S_i^* \end{bmatrix}$

Spatial multiplexing mode : $B = \begin{bmatrix} S_i \\ S_{i+1} \end{bmatrix}$ where S_i and S_{i+1} may be encoded in different rates.

~~TxAA mode : $C = S_i \begin{bmatrix} w_0 \\ w_1 \end{bmatrix}$, where $w_{0,1}$ are the fed-back antenna weight coefficients from SS through the fast feedback channels such as CQI channel and its mapping shall be done as shown in Figure 231. With w0 = 1, BS may implement a simplified beamforming transmission. Furthermore, antenna selection diversity is achieved when one of wi = 0. In order to facilitate fast and accurate adaptation for multiple antennas, BS may use multiple CQI channels to a certain SS (See 8.4.5.3.12.1).~~

[Add a new section 8.4.8.4.3]

8.4.8.4.3 Transmission schemes for 2-antenna SS in UL

The following matrices define the transmission format with the row index indicating antenna number and column index indicating OFDMA symbol time. For both UL permutation zones with 2-antenna SS, one of the following two transmission matrices shall be used:

Diversity mode : $A = \begin{bmatrix} S_i & -S_{i+1}^* \\ S_{i+1} & S_i^* \end{bmatrix}$

Spatial multiplexing mode : $B = \begin{bmatrix} S_i \\ S_{i+1} \end{bmatrix}$ where S_i and S_{i+1} may be encoded in different rates.

The mode B may also be used for two single antenna SS to share the same subchannel (collaborative spatial multiplexing).

3.2. Transmission Schemes for 4 Tx

Due to high computational complexity, most communication system would not use the full-diversity full-rate (FDFR) codes even though their performance is good. In [16d], space time block codes for 4 transmit antennas are used for optional FUSC and AMC zones. However, this scheme is outperformed by the proposed FDFR space-time codes. In fact, the diversity gain of the latter is the doubled than that of the former.

3.2.1. Conventional Full Diversity Full Rate STBC

In [2-4], they use the Vandermonde matrix to achieve the full diversity full rate.

$$\mathbf{S}' = \Theta\mathbf{S} = \frac{\mathbf{1}}{\sqrt{\mathbf{4}}}\begin{bmatrix} 1 & \alpha_0^1 & \alpha_0^2 & \alpha_0^3 \\ 1 & \alpha_1^1 & \alpha_1^2 & \alpha_1^3 \\ 1 & \alpha_2^1 & \alpha_2^2 & \alpha_2^3 \\ 1 & \alpha_3^1 & \alpha_3^2 & \alpha_3^3 \end{bmatrix}\begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{bmatrix} = \begin{bmatrix} S_1' \\ S_2' \\ S_3' \\ S_4' \end{bmatrix}$$

where $\alpha_i = \exp(2\pi(i+1/4)/4), \quad i = 0,1,\ldots,3$

Xin [2] and Ma [3] use diagonal channel matrix after multiplying the information symbols by the Vandermonde matrix. This linear precoding is referred to as the constellation rotating operation. Notice that the coding advantage of [2] and [3] is not optimized, although the schemes successfully achieve FDFR. Jung [4] improves the coding advantages by concatenating the constellation rotating precoder with the basic Alamouti scheme, resulting in the following transmitted signals:

$$\mathbf{S} = \begin{bmatrix} S_1 & S_2 & 0 & 0 \\ -S_2^* & S_1^* & 0 & 0 \\ 0 & 0 & S_3 & S_4 \\ 0 & 0 & -S_4^* & S_3^* \end{bmatrix}$$

As we already mentioned, this kind of precoder require the ML decoder. When the ML decoder relies on exhaustive search, it has complexity $O(M^N)$, which is prohibitively high for the large block size N and the constellation size M. So, they tried to propose the suboptimum decoding algorithm.

3.2.2. Coding Advantages

Definition of coding advantages :

$$\mathbf{P}((S_1,S_2),(S_3,S_4)) = diag(\mathbf{P}_{Ala}(S_1,S_2),\mathbf{P}_{Ala}(S_3,S_4))$$

where, $\mathbf{P}_{Ala}(a,b) \triangleq 1/\sqrt{2}\begin{bmatrix} a & -b^* \\ b & a^* \end{bmatrix}$. For this code, the determinant of the matrix for distinct input vectors is as follows

$$\begin{aligned}\xi_4 &= \det\left(\mathbf{P}(\mathbf{S}-\mathbf{S}')\mathbf{P}(\mathbf{S}-\mathbf{S}')\right) = \prod_{i=1}^{2}\det\left(\mathbf{P}_{Ala}^{H}(S_{2i-1},S_{2i})\mathbf{P}_{Ala}(S_{2i-1},S_{2i})\right)\\ &= \prod_{i=1}^{2}\det\left(\frac{1}{2}\begin{bmatrix}|S_{2i-1}|^2+|S_{2i}|^2 & 0\\ 0 & |S_{2i-1}|^2+|S_{2i}|^2\end{bmatrix}\right)\\ &= \prod_{i=1}^{2}\left(|S_{2i-1}|^2+|S_{2i}|^2\right)^2/4\end{aligned}$$

The value $\xi_{\min,N} \triangleq \min_{\mathbf{r}\neq\mathbf{r}'} \xi_N$ will be referred to as the minimum coding advantage.

$$\left(\xi_N^{Samsung}\right)^{N/2} = \min_{\mathbf{S},\mathbf{S}'}\left[\prod_{i=1}^{2}\left(|S_{2i-1}|^2+|S_{2i}|^2\right)^2/4\right]^{1/2}$$

In order to achieve the maximum coding advantage, we did two different approaches, one based on number theory and another based on computer search. But, in this document we just show the result of the computer based search.

Fig. 2 shows the coding advantage as a function of phase θ_1 and θ_2. We maximize the coding advantage by computer search over θ_1 and θ_2 in the domain 0 to 2π. Based on computer search, we obtain a general equation to achieve maximum coding advantage as follows

$$|\theta_1 - \theta_2| = \pi$$

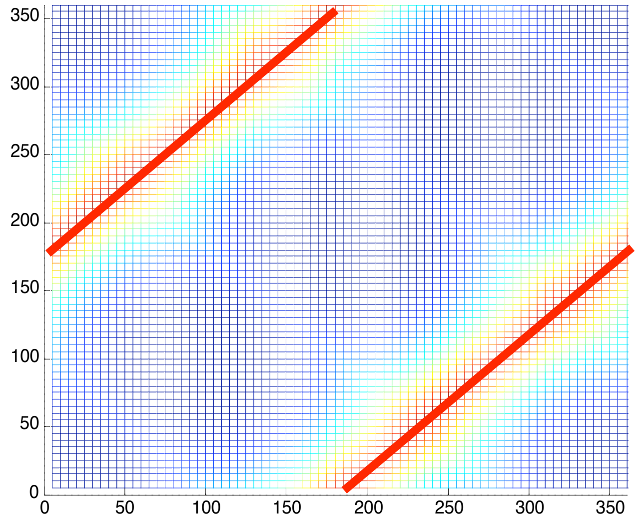


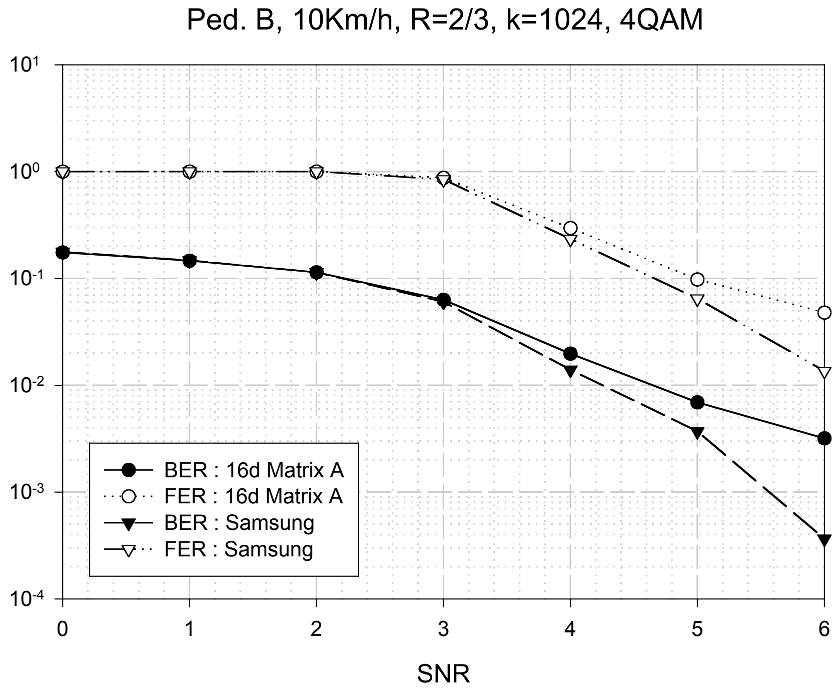
Fig 2. Coding advantages as a function of phase θ_1 and θ_2

3.2.3. Proposed Precoding Scheme

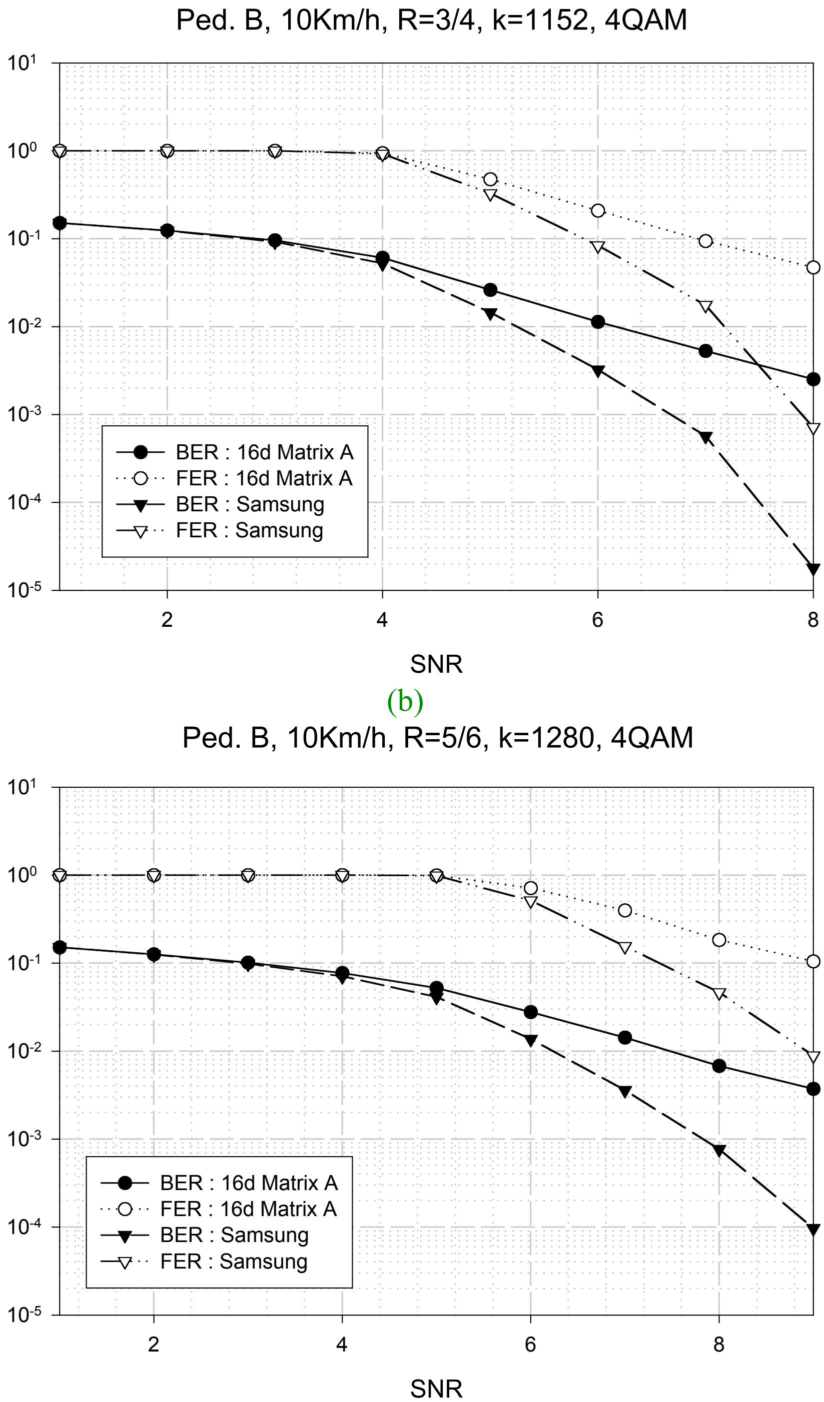
We propose a puncturing and shifting procedures after the constellation rotation process resulting in a new precoder scheme. That is

$$\begin{bmatrix} S_i' \\ S_{i+1}' \\ S_{i+2}' \\ S_{i+3}' \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & \alpha_0^1 & 0 & 0 \\ 0 & 0 & 1 & \alpha_0^1 \\ 1 & \alpha_1^1 & 0 & 0 \\ 0 & 0 & 1 & \alpha_1^1 \end{bmatrix} \begin{bmatrix} S_i \\ S_{i+1} \\ S_{i+2} \\ S_{i+3} \end{bmatrix}$$

where, $\alpha_0^1 = e^{j\theta_1}, \alpha_1^1 = e^{j\theta_2}, \left(|\theta_1 - \theta_2| = \pi\right)$ S represent the information symbols and S' are the new generated symbols by the proposed precoder. The proposed scheme performs better than or as good as other constellation-rotation approaches, but with a significantly lower receiver complexity. Fig 3 shows the average bit error rate and frame error rate for proposed precoder used in conjunction with the Alamouti code for 4 Tx and 1 Rx, using rotation matrix constructed as discussed in section 3.2.1. The results are compared to those of the IEEE802.16d Matrix A. As can be observed, the proposed precoder outperforms the reference system under various environments.



(a)



(b)

(c)

Fig. 3 BER/FER performance for 4 Tx 1 Rx,
(a : R=2/3, b : R=3/4, c : R=5/6)

3.2.4. Specific Text Changes

[Replace the section 8.4.8.3.5 with the following]

8.4.8.3.5 Transmission schemes for 4-antenna BS in DL

For both permutation zones with 4-antenna BS, one of the following ~~four~~ three transmission matrices shall be used:

Diversity mode : $A = \begin{bmatrix} S_i' & -(S_{i+1})^* & 0 & 0 \\ S_{i+1}' & (S_i)^* & 0 & 0 \\ 0 & 0 & S_{i+2}' & -(S_{i+3})^* \\ 0 & 0 & S_{i+3}' & (S_{i+2})^* \end{bmatrix}$

where,

$$\begin{bmatrix} S_i' \\ S_{i+1}' \\ S_{i+2}' \\ S_{i+3}' \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & \alpha_0^1 & 0 & 0 \\ 0 & 0 & 1 & \alpha_0^1 \\ 1 & \alpha_1^1 & 0 & 0 \\ 0 & 0 & 1 & \alpha_1^1 \end{bmatrix} \begin{bmatrix} S_i \\ S_{i+1} \\ S_{i+2} \\ S_{i+3} \end{bmatrix}$$

Hybrid mode : , $B = \begin{bmatrix} S_i & -(S_{i+1})^* & S_{i+4} & -(S_{i+6})^* \\ S_{i+1} & (S_i)^* & S_{i+5} & -(S_{i+7})^* \\ S_{i+2} & -(S_{i+3})^* & S_{i+6} & -(S_{i+4})^* \\ S_{i+3} & (S_{i+2})^* & S_{i+7} & (S_{i+5})^* \end{bmatrix}$

Spatial multiplexing mode : $C = \begin{bmatrix} S_i \\ S_{i+1} \\ S_{i+2} \\ S_{i+3} \end{bmatrix}$

~~TxAA mode :~~ ~~$D = S_i \begin{bmatrix} w_0 \\ w_1 \\ w_2 \\ w_3 \end{bmatrix}$~~

3.3. Mode Selection Feedback

As mentioned earlier, for the efficient MIMO operation in DL, SS needs to report the most appropriate MIMO mode(s) to BS. The current draft standard, however, is not clear on this.

[Modify the Table 296a in Section 84.5.4.10.3 in page 77 in [1]]

8.4.5.4.10.3 Mode Selection Feedback

Table 296 – Encoding of payload bits for Fast-feedback slot

Value	Description
0b0000	STTD and PUSC/FUSC permutation
0b0001	STTD and adjacent-subcarrier permutation
0b0010	SM and PUSC/FUSC permutation
0b0011	SM and adjacent-subcarrier permutation
0b0100	Hybrid~~Closed-loop SM~~ and PUSC/FUSC permutation
0b0101	Hybrid and adjacent-subcarrier permutation ~~Closed-loop SM and adjacent-subcarrier permutation~~
~~0b0110~~	~~Closed-loop SM + Beamforming and adjacent-subcarrier permutation~~
~~0b0111~~	~~TD + Beamforming and adjacent-subcarrier permutation~~
0b0110~~1000~~ - 1111	Reserved

References:

[1] IEEE P802.16e/D3 Air Interface for Fixed and Mobile Broadband Wireless Access Systems – Amendment for Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands

[2] Y. Xin, Z. Wang, and G.B. Giannakis, "Space-time diversity systems based on linear constellation precoding," IEEE Trans. Wireless Commun., vol. 2, no. 2, pp.294-309, Mar. 2003

[3] X. Ma and G.B. Giannakis, "Complex field coded MIMO systems: performance, rate, and trade-offs," Wirel. Commun. Mob. Comput. pp. 693-717, 2002

[4] T.J.Jung and K.Cheun, "Design of concatenated space-time block codes using signal space diversity and the Alamouti sheme," IEEE Commun. Letters vol. 7, no. 7, pp.329-331, July 2003