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Title	**Enhancement of Rate 2 STC with Antenna Grouping**
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Re:	Contribution supporting TGe WG ballot #14d
Abstract	Enhancement of Rate 2 STC with Antenna Grouping
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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Enhancement of Rate 2 STC with Antenna Grouping

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1. Introduction

In order to exploit both spatial diversity and spatial multiplexing gain, the rate 2 STC is described as matrix *B* for three and four transmit antennas [1]. In this contribution, we propose a *simple antenna grouping* based on closed-loop precoding method. The proposed closed loop scheme requires only *three bit or less* feedback and can provide considerable performance gain over the current open loop scheme.

2. Antenna grouping for 3 transmit-antenna rate 2 STC

A space-time-frequency code (over two OFDMA symbols and two sub-carriers) for 3Tx-Rate 2 configuration was introduced in the current standard [1]. Its matrix representation is the following.

$$B_1 = \begin{bmatrix} \sqrt{\frac{3}{4}} & 0 & 0 \\ 0 & \sqrt{\frac{3}{4}} & 0 \\ 0 & 0 & \sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} \tilde{s}_1 & -\tilde{s}_2^* & \tilde{s}_5 & -\tilde{s}_6^* \\ \tilde{s}_2 & \tilde{s}_1^* & \tilde{s}_6 & \tilde{s}_5^* \\ \tilde{s}_7 & -\tilde{s}_8^* & \tilde{s}_3 & -\tilde{s}_4^* \end{bmatrix}$$

$$B_2 = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix} B_1 \qquad (1)$$

and

$$B_3 = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} B_1$$

In above matrix B, s_3, s_4, s_7, and s_8 will be transmitted through only one antenna with diversity order of one while other symbols will be transmitted through two antennas with diversity order of two. This approach offers a solution when the

BS does not know the channel information. However, if the BS can use the partial channel information which is transmitted by the MS, the matrix B could be adapted based on channel quality.

When SS reports 0b110010 on its allocated CQICH, then BS shall transmit in the following transmission matrix

$$B_1 = \begin{bmatrix} \tilde{s}_7 & -\tilde{s}_8^* & \tilde{s}_3 & -\tilde{s}_4^* \\ \tilde{s}_1 & -\tilde{s}_2^* & \tilde{s}_5 & -\tilde{s}_6^* \\ \tilde{s}_2 & \tilde{s}_1^* & \tilde{s}_6 & \tilde{s}_5^* \end{bmatrix}, \quad \text{where antenna 1 has the best associated channel.}$$

When SS reports 0b110011 on its allocated CQICH, then BS shall transmit in the following transmission matrix

$$B_2 = \begin{bmatrix} \tilde{s}_1 & -\tilde{s}_2^* & \tilde{s}_5 & -\tilde{s}_6^* \\ \tilde{s}_7 & -\tilde{s}_8^* & \tilde{s}_3 & -\tilde{s}_4^* \\ \tilde{s}_2 & \tilde{s}_1^* & \tilde{s}_6 & \tilde{s}_5^* \end{bmatrix}, \quad \text{where antenna 2 has the best associated channel.}$$

When SS reports 0b110100 on its allocated CQICH, then BS shall transmit in the following transmission matrix

$$B_3 = \begin{bmatrix} \tilde{s}_1 & -\tilde{s}_2^* & \tilde{s}_5 & -\tilde{s}_6^* \\ \tilde{s}_2 & \tilde{s}_1^* & \tilde{s}_6 & \tilde{s}_5^* \\ \tilde{s}_7 & -\tilde{s}_8^* & \tilde{s}_3 & -\tilde{s}_4^* \end{bmatrix}, \quad \text{where antenna 3 has the best associated channel.}$$

3. Antenna grouping for 4 transmit-antenna rate 2 STC

The rate 2 transmission code for 4 transmit antennas in the current standard [1] is

$$B = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_2 & s_1^* & s_6 & -s_8^* \\ s_3 & -s_4^* & s_7 & s_5^* \\ s_4 & s_3^* & s_8 & s_6^* \end{bmatrix} \quad (1)$$

The first two columns correspond to a subcarrier and the last two columns correspond to the adjacent subcarrier. When the MIMO precoding is used, the following 4-by-4 weight matrix is multiplied to matrix *B* before transmitted through transmit antennas.

$$\mathbf{W} = \begin{bmatrix} w_{11} & w_{12} & w_{13} & w_{14} \\ w_{21} & w_{22} & w_{23} & w_{24} \\ w_{31} & w_{32} & w_{33} & w_{34} \\ w_{41} & w_{42} & w_{43} & w_{44} \end{bmatrix} \quad (2)$$

According to the number of available feedback bits, candidates for **W** can vary. When 3bit feedback information is available, antenna grouping matrix **W** is selected among the following matrix $\mathbf{W}_1$~ $\mathbf{W}_6$:

$$\mathbf{W}_1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad \mathbf{W}_2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}, \quad \mathbf{W}_3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix},$$

$$\mathbf{W}_4 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, \quad \mathbf{W}_5 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \end{bmatrix}, \quad \mathbf{W}_6 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}. \tag{3}$$

Once the optimum weight matrix for the first two columns of matrix B is determined, the optimum weight matrix for the last two columns is automatically determined. The one-to-one mapping rule is as follows:
($\mathbf{W}_1$ – $\mathbf{W}_3$), ($\mathbf{W}_2$ – $\mathbf{W}_5$), ($\mathbf{W}_3$ – $\mathbf{W}_1$), ($\mathbf{W}_4$ – $\mathbf{W}_6$), ($\mathbf{W}_5$ – $\mathbf{W}_2$), ($\mathbf{W}_6$ – $\mathbf{W}_4$).
~~If only 2 bits feedback is available, $\mathbf{W}_1$, $\mathbf{W}_3$, $\mathbf{W}_5$ are used.~~

Then according to the antenna grouping feedback information, transmission matrix B for rate 2 may be improved with antenna grouping information which is fed back on a CQICH from SS.

When SS reports 0b110010 on its allocated CQICH, then BS shall group antenna 0 and 1 for the first diversity pair and antenna 1 and 2 for the second diversity pair. In matrix form, it shall be read as

$$B_1 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_2 & s_1^* & s_7 & s_5^* \\ s_3 & -s_4^* & s_6 & -s_8^* \\ s_4 & s_3^* & s_8 & s_6^* \end{bmatrix}$$

When SS reports 0b110011 on its allocated CQICH, then BS shall transmit in the following transmission matrix

$$B_2 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_2 & s_1^* & s_7 & s_5^* \\ s_4 & s_3^* & s_8 & s_6^* \\ s_3 & -s_4^* & s_6 & -s_8^* \end{bmatrix}$$

When SS reports 0b110100 on its allocated CQICH, then BS shall group antenna 0 and 2 for the first diversity pair and antenna 1 and 3 for the second diversity pair. In matrix form, it shall be read as

$$B_3 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_3 & -s_4^* & s_6 & -s_8^* \\ s_2 & s_1^* & s_7 & s_5^* \\ s_4 & s_3^* & s_8 & s_6^* \end{bmatrix}$$

When SS reports 0b110101 on its allocated CQICH, then BS shall transmit in the following transmission matrix

$$B_4 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_4 & s_3^* & s_8 & s_6^* \\ s_2 & s_1^* & s_7 & s_5^* \\ s_3 & -s_4^* & s_6 & -s_8^* \end{bmatrix}$$

When SS reports 0b110110 on its allocated CQICH, then BS shall group antenna 0 and 3 for the first diversity pair and antenna 1 and 2 for the second diversity pair. In matrix form, it shall be read as

$$B_5 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_3 & -s_4^* & s_6 & -s_8^* \\ s_4 & s_3^* & s_8 & s_6^* \\ s_2 & s_1^* & s_7 & s_5^* \end{bmatrix}$$

When SS reports 0b110111 on its allocated CQICH, then BS shall transmit in the following transmission matrix

$$B_6 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_4 & s_3^* & s_8 & s_6^* \\ s_3 & -s_4^* & s_6 & -s_8^* \\ s_2 & s_1^* & s_7 & s_5^* \end{bmatrix}$$

Assuming that adjacent two subcarriers have identical channel parameters and quasi-static over two OFDM symbols, for the simplicity, we can consider only the first two columns of matrix *B*. If the antenna grouping matrix for the first two columns is determined, the matrix for the other two columns is automatically determined. Let $y_{r,i}$ be the received signal at the *i*-th symbol time at the *r*-th receive antenna, and $h_{t,r}$ denote the channel parameter between the *t*-th transmit and *r*-th receive antenna. When the number of receive antennas is two, the received signal can be represented as

$$\mathbf{y} = \mathbf{X}(\mathbf{HW})\mathbf{s} + \mathbf{v} \tag{4}$$

where $\mathbf{y} = [y_{1,1} \quad y_{1,2}^* \quad y_{2,1} \quad y_{2,2}^*]^T$, $\mathbf{s} = [s_1 \quad s_2 \quad s_3 \quad s_4]^T$, $\mathbf{v}$ is the noise vector, $\mathbf{H} = \begin{bmatrix} h_{1,1} & h_{2,1} & h_{3,1} & h_{4,1} \\ h_{1,2} & h_{2,2} & h_{3,2} & h_{4,2} \end{bmatrix}$, and $\mathbf{X}(\cdot)$ is a function of 2-by-4 input matrix which is defined as

$$\mathbf{X}\left(\begin{bmatrix} a & b & c & d \\ e & f & g & h \end{bmatrix}\right) = \begin{bmatrix} a & b & c & d \\ b^* & -a^* & d^* & -c^* \\ e & f & g & h \\ f^* & -e^* & h^* & -g^* \end{bmatrix}. \tag{5}$$

At the mobile station, ~~the index of **W**~~, the index of the transmission matrix $\mathbf{B}_q$ is determined based on the following criteria:

$$q = \arg\min_{l=1,\cdots,6}\left[abs\left(\det(\mathbf{H}_{l,1}) + \det(\mathbf{H}_{l,2})\right)\right] \tag{6}$$

where $\mathbf{H}_{l,1}$ is the first two columns of $\mathbf{HW}_l$ and $\mathbf{H}_{l,2}$ is the last two columns of $\mathbf{HW}_l$. Note that the antenna grouping matrix selection rule in (6) is equivalent to the following rule:

$$q = \arg\min_{l=1,\cdots,6}\left[trace\left(\left[(\mathbf{X}(\mathbf{HW}_l))^H \mathbf{X}(\mathbf{HW}_l)\right]^{-1}\right)\right] . \tag{7}$$

Alternate criteria for the antenna grouping can be applied to determine antenna group index. For example, minimize BER, minimum mean square error, etc.

4. Simulation results

We compare the proposed antenna grouping based closed-loop STC with open-loop STC for 4 transmit-antenna rate 2 STC. In Fig.1 ~ Fig. ~~4~~2, packet error rates of the proposed antenna grouping method and the conventional open loop STC (matrix *B*) method are compared in the pedestrian A channel with 3km/h. One ~~Two~~ frame feedback delay is reflected in the simulation and MMSE linear detector is used at the receiver.

When the correlation coefficient is 0.2 (Fig. 1), the proposed antenna grouping with 3bit feedback outperforms the conventional STC without antenna grouping more than 1.8 dB at PER = 10^{-2} (1.8 dB for 1/2 rate QPSK, 2.5 dB for 1/2 rate 16QAM, 2.4 dB for 1/2 rate 64QAM, and 3.2 dB for 2/3 rate 64QAM). As higher MCS level is used, the performance gain is increased. Even if the correlation coefficient increases up to 0.7, the performance gain of the proposed antenna grouping still remains as the same.

In Fig.3 ~ Fig. 4, goodputs of the proposed antenna grouping and the conventional matrix B are compared. At the same SNR, the proposed antenna grouping outperforms a maximum of 1.7 bits/subcarrier over the conventional open loop scheme regardless of the value of antenna correlation.

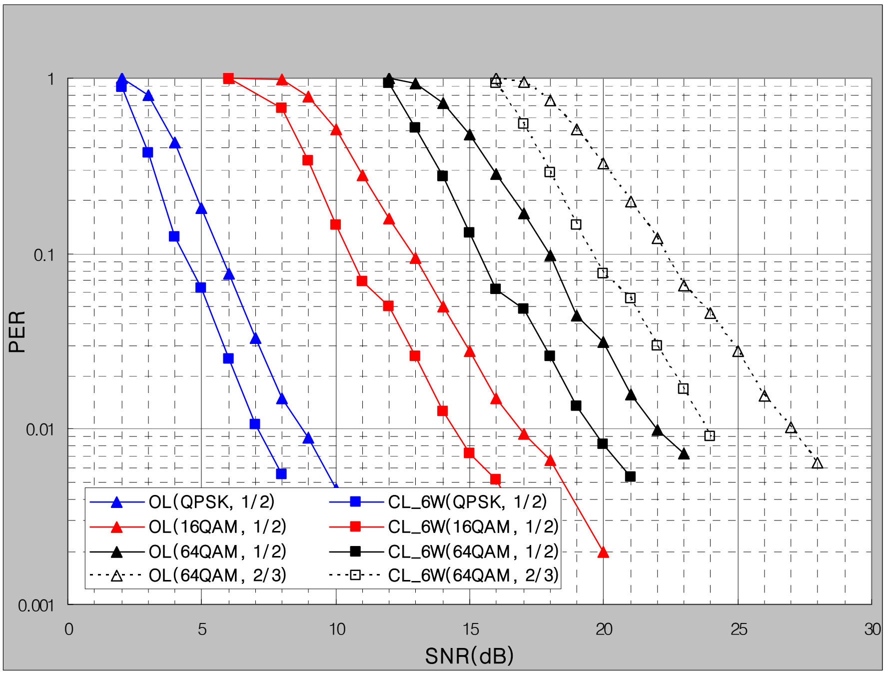


Fig.1. PER vs. SNR with and without antenna grouping when the correlation coefficient = 0.2
(CTC, Band AMC with 2-by-6 block, one feedback per each AMC block, OL denotes conventional open loop CTC, CL_6W denotes proposed antenna grouping)

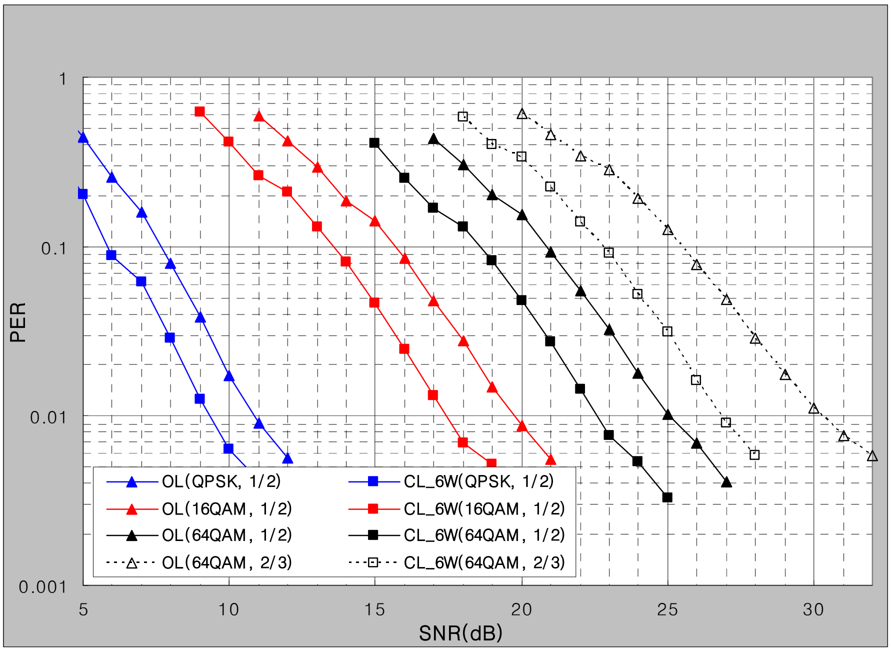


Fig.2. PER vs. SNR with and without antenna grouping when the correlation coefficient = 0.7.

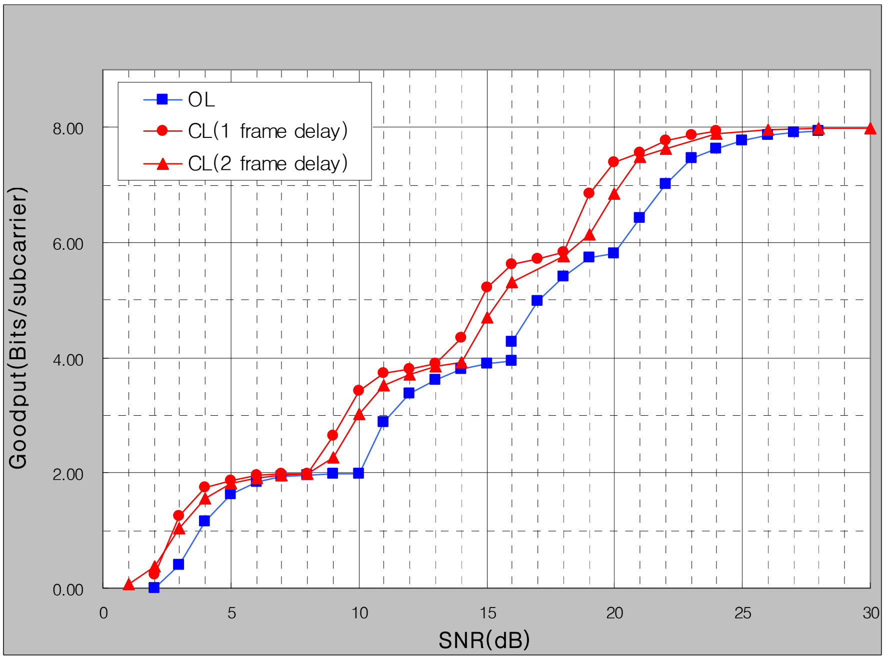


Fig.3. Goodput vs. SNR with and without antenna grouping when the correlation coefficient = 0.2 (OL denotes conventional open loop STC, CL denotes the proposed antenna grouping)

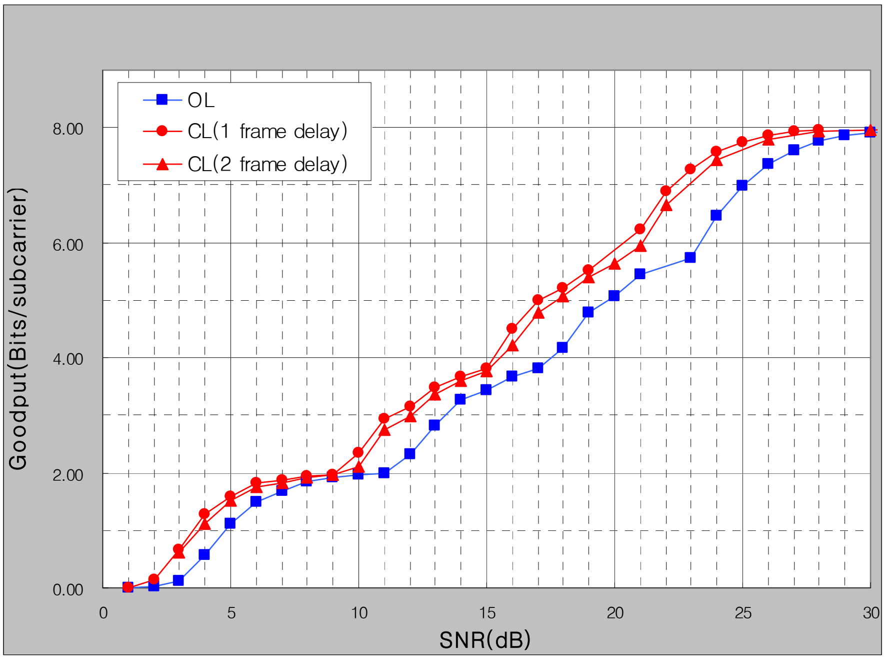


Fig.4. Goodput vs. SNR with and without antenna grouping when the correlation coefficient = 0.7 (OL denotes conventional open loop STC, CL denotes the proposed antenna grouping)

~~In the pedestrian A channel with 3km/h (Fig. 1 ~ Fig. 3), the proposed antenna grouping with 3bit feedback outperforms the conventional STC without antenna grouping more than 1.8dB at PER = 10^{-2} (1.8dB for 1/2 rate QPSK, 2.4 dB for 1/2 rate 16QAM, and 3.7dB for 3/4 rate 16QAM). Even if the number of grouping matrix candidates are reduced as three (2 bit feedback), the performance loss is only 0.5dB and the proposed antenna grouping still shows significant performance gain. Fig. 4 shows the PER performance comparison results in the pedestrian B with 10km/h. Because the frequency and time selectivity are increased, performance gain of the proposed antenna grouping is reduced, but still 0.5dB gain can be achieved.~~

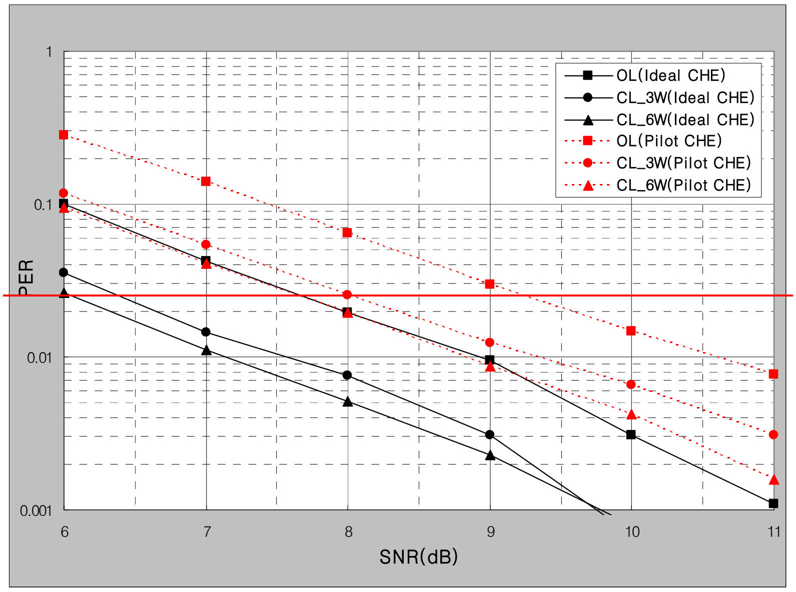


Fig.1. PER vs. SNR with and without antenna grouping
(CTC 1/2 rate, QPSK, Band AMC with 2-by-6 block, one feedback per each AMC block, Ped.A 3km/h, uncorrelated channel , OL denotes conventional open loop CTC, CL_3W denotes antenna grouping with 2bit feedback, CL_6W denotes antenna grouping with 3bit feedback)

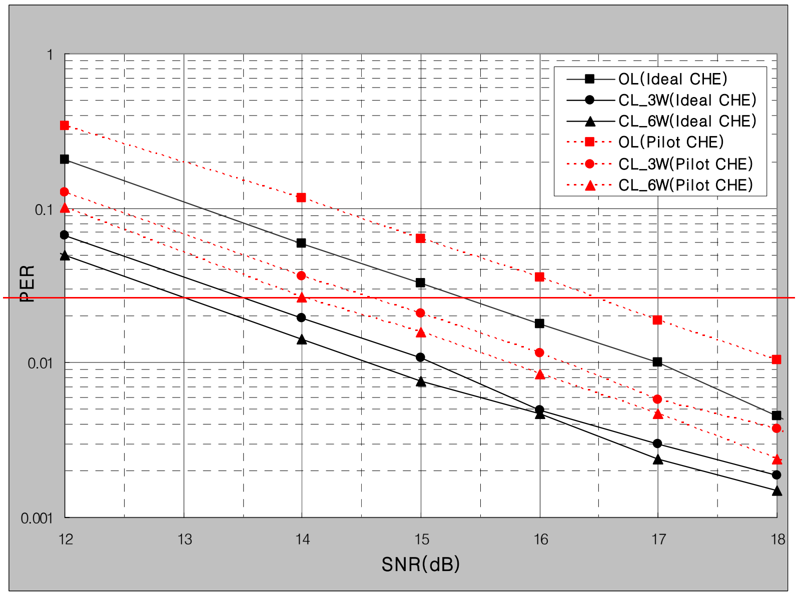
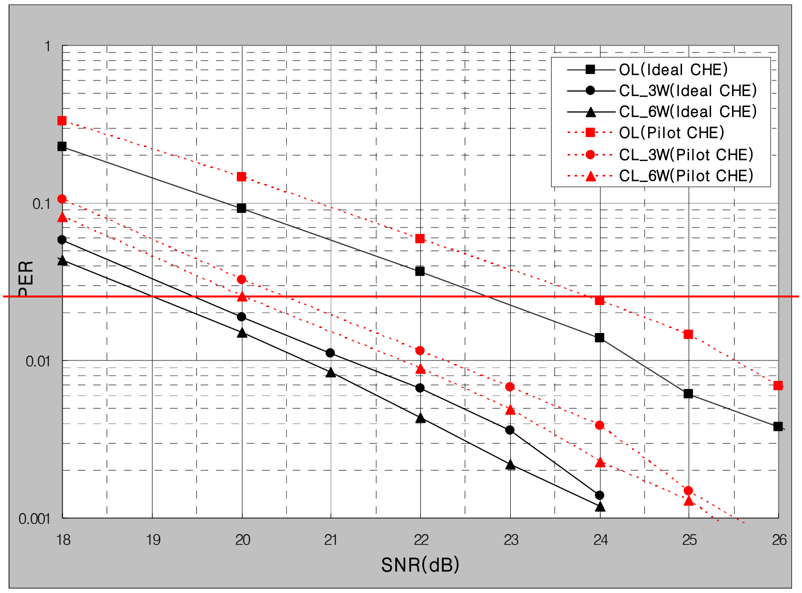
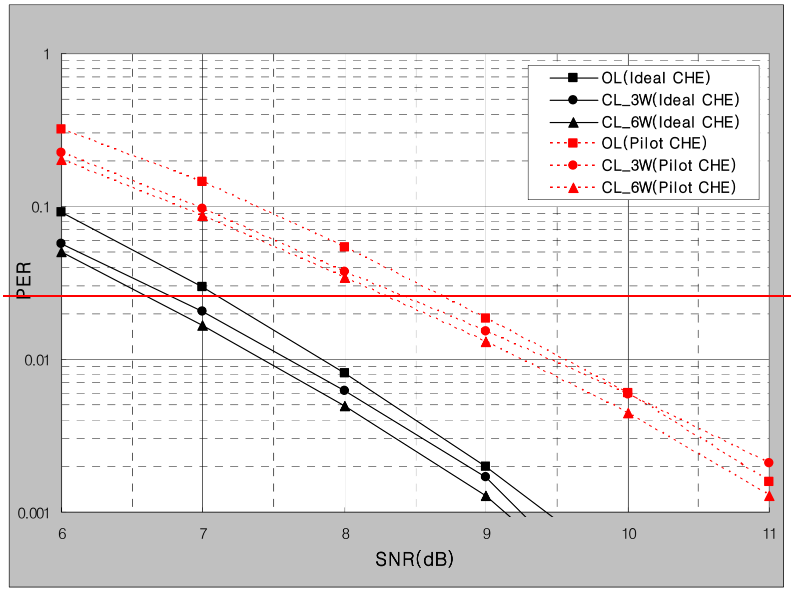


Fig.2. PER vs. SNR with and without antenna grouping
(CTC 1/2 rate, 16QAM, Band AMC with 2-by-6 block, one feedback per each AMC block, Ped.A 3km/h, uncorrelated channel)



~~Fig.3. PER vs. SNR with and without antenna grouping~~
~~(CTC 3/4 rate, 16QAM, Band AMC with 2-by-6 block, one feedback per each AMC block, Ped.A 3km/h, uncorrelated channel)~~



~~Fig.4. PER vs. SNR with and without antenna grouping~~
~~(CTC 1/2 rate, QPSK, Band AMC with 2-by-6 block, one feedback per each AMC block, Ped.B 10km/h, uncorrelated channel)~~

5. Specific Text Changes

[Add a new section 8.4.8.3.5.2 as follows]

8.4.8.3.4.2 Enhanced Rate 2 Transmission with Antenna Grouping

For 3 Tx antenna BS, transmission matrix B for rate 2 may be improved with antenna grouping information which is fed back on a CQICH from SS.

When SS reports 0b110010 on its allocated CQICH, then BS shall transmit in the following transmission matrix

$$B_1 = \begin{bmatrix} \tilde{s}_7 & -\tilde{s}_8^* & \tilde{s}_3 & -\tilde{s}_4^* \\ \tilde{s}_1 & -\tilde{s}_2^* & \tilde{s}_5 & -\tilde{s}_6^* \\ \tilde{s}_2 & \tilde{s}_1^* & \tilde{s}_6 & \tilde{s}_5^* \end{bmatrix}$$

When SS reports 0b110011 on its allocated CQICH, then BS shall transmit in the following transmission matrix

$$B_2 = \begin{bmatrix} \tilde{s}_1 & -\tilde{s}_2^* & \tilde{s}_5 & -\tilde{s}_6^* \\ \tilde{s}_7 & -\tilde{s}_8^* & \tilde{s}_3 & -\tilde{s}_4^* \\ \tilde{s}_2 & \tilde{s}_1^* & \tilde{s}_6 & \tilde{s}_5^* \end{bmatrix}$$

When SS reports 0b110100 on its allocated CQICH, then BS shall transmit in the following transmission matrix

$$B_3 = \begin{bmatrix} \tilde{s}_1 & -\tilde{s}_2^* & \tilde{s}_5 & -\tilde{s}_6^* \\ \tilde{s}_2 & \tilde{s}_1^* & \tilde{s}_6 & \tilde{s}_5^* \\ \tilde{s}_7 & -\tilde{s}_8^* & \tilde{s}_3 & -\tilde{s}_4^* \end{bmatrix}$$

[Add a new section 8.4.8.3.5.2 as follows]

8.4.8.3.5.2 Enhanced Rate 2 Transmission with Antenna Grouping

For 4 Tx antenna BS, transmission matrix B for rate 2 may be improved with antenna grouping information which is fed back on a CQICH from SS.

When SS reports 0b110010 on its allocated CQICH, then BS shall group antenna 0 and 1 for the first diversity pair and antenna 1 and 2 for the second diversity pair. In matrix form, it shall be read as

$$B_1 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_2 & s_1^* & s_7 & s_5^* \\ s_3 & -s_4^* & s_6 & -s_8^* \\ s_4 & s_3^* & s_8 & s_6^* \end{bmatrix}$$

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When SS reports 0b110100 on its allocated CQICH, then BS shall group antenna 0 and 2 for the first diversity pair and antenna 1 and 3 for the second diversity pair. In matrix form, it shall be read as

$$B_3 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_3 & -s_4^* & s_6 & -s_8^* \\ s_2 & s_1^* & s_7 & s_5^* \\ s_4 & s_3^* & s_8 & s_6^* \end{bmatrix}$$

When SS reports 0b110101 on its allocated CQICH, then BS shall transmit in the following transmission matrix

$$B_4 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_4 & s_3^* & s_8 & s_6^* \\ s_2 & s_1^* & s_7 & s_5^* \\ s_3 & -s_4^* & s_6 & -s_8^* \end{bmatrix}$$

When SS reports 0b110110 on its allocated CQICH, then BS shall group antenna 0 and 3 for the first diversity pair and antenna 1 and 2 for the second diversity pair. In matrix form, it shall be read as

$$B_5 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_3 & -s_4^* & s_6 & -s_8^* \\ s_4 & s_3^* & s_8 & s_6^* \\ s_2 & s_1^* & s_7 & s_5^* \end{bmatrix}$$

When SS reports 0b110111 on its allocated CQICH, then BS shall transmit in the following transmission matrix

$$B_6 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_4 & s_3^* & s_8 & s_6^* \\ s_3 & -s_4^* & s_6 & -s_8^* \\ s_2 & s_1^* & s_7 & s_5^* \end{bmatrix}$$

References:

[1] IEEE P802.16-REVd/D5-2004 Draft IEEE Standards for local and metropolitan area networks part 16: Air interface for fixed broadband wireless access systems