Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**A Space-Time Code With Full-Diversity and Rate 2 for 2 Transmit Antenna Transmission**
Date Submitted	**2004-11-11**
Source(s)	**Seung Joon Lee, Choong Il Yeh, Hyoungsoo Lim, In Kyeong Choi, Jong Ee Oh, Kwang Jae Lim, Seong Rag Kim, Young Seog Song, Yu Ro Lee, Dong Seung Kwon, Seung Ku Whang** ETRI 161 Gajeong-dong, Yuseong-gu, Daejeon, 305-350 Korea E-mail: s.j.lee@etri.re.kr Tel: +82-42-860-5207 **Seong Keun Oh, Moon Il Lee, Ki Bum Kwon, Heegoo Han** Ajou University, San 5, Wonchon-Dong, Yeongtong-Gu, Suwon, 443-749, Korea E-mail: oskn@ajou.ac.kr Tel: +82-31-219-2370
Re:	P802.16e/D5
Abstract	To propose to add a space-time code with full-diversity and full-rate for 2 transmit antenna transmission.
Purpose	Adoption of proposed changes into P802.16e/D6
Notice	
Release	
Patent Policy and Procedures	

A Full-Diversity Space-Time Code With Rate 2 for 2 Transmit Antenna Transmission

Seung Joon Lee, Choong Il Yeh, Hyoungsoo Lim, In Kyeong Choi, Jong Ee Oh, Kwang Jae Lim, Seong Rag Kim, Young Seog Song, Yu Ro Lee, Dong Seung Kwon, Seung Ku Whang

ETRI

Seong Keun Oh, Moon Il Lee, Ki Bum Kwon, Heegoo Han

Ajou University

1 Introduction

We propose an enhanced space-time code (STC) with the full-rate and full-diversity for 2 transmit antenna transmission. In the current draft standard [1], there are two space-time matrices A and B for 2 transmit antenna transmission in BS. The matrix A has full diversity advantage but its rate is limited to 1. The matrix B has the highest rate of 2 but achieves only half of the full diversity advantage. Although the matrix B is efficiently used especially when the rate adaptation is required, that is, two parallel symbols to be simultaneously transmitted are encoded in different rates (in different QAM orders), it is recommended to additionally adopt a rate 2 STC with higher diversity advantage and coding gain for high rate transmission with improved quality. A full diversity STC with rate 2 is proposed for this purpose in this contribution. While this code is specified as a space-time code, it may also be used as a space-frequency code or as a hybrid.

After introduction of the proposed STC, its performance is compared with the matrix B by using computer simulations and also comparison with the Golden code known to be the best in public is addressed. Suggestion of Specific Text Changes follows. Finally derivation of the proposed STC is presented in Appendix.

2 Proposed STC for 2 transmit antenna transmission

We propose to add the following transmission matrix for 2 transmit antenna transmission:

$$C = \frac{1}{\sqrt{1+r^2}} \begin{pmatrix} s_1 + jr \cdot s_4 & r \cdot s_2 + s_3 \\ s_2 - r \cdot s_3 & jr \cdot s_1 + s_4 \end{pmatrix}$$

where $r = \frac{-1+\sqrt{5}}{2}$.

The proposed change is managed by the fact that the new transmission matrix C provides the full diversity gain (the diversity order of two times the number of the receive antennas), while maintaining the rate or multiplexing gain of the existing transmission matrix B in Section 8.4.8.3.3. The new matrix

C with the full rate of 2 transmits four symbols over two OFDM symbol times (cf., two symbols over one OFDM symbol time in the matrix B). Using the proposed code, the full diversity gain is achieved by transmitting each data symbol so that it experiences all the possible branches in the MIMO channel over two OFDM symbol times while maintaining the code error matrix of rank 2. Then, the code has been designed so that the pair-wise error probability between codewords could be minimized in order to maximize the coding gain. The proposed STC can be applied to all QPSK, 16QAM, and 64QAM. The code admits decoding with a simple decoding algorithm as the typical decoding algorithm for the matrix B.

3 Performance Evaluation

3.1 Simulation Results

Fig. 1 shows the uncoded bit error rate performance of the proposed code compared with that of the matrix B . Additionally Fig.2 shows the comparison of the coded bit error performance between the proposed code and the matrix B.

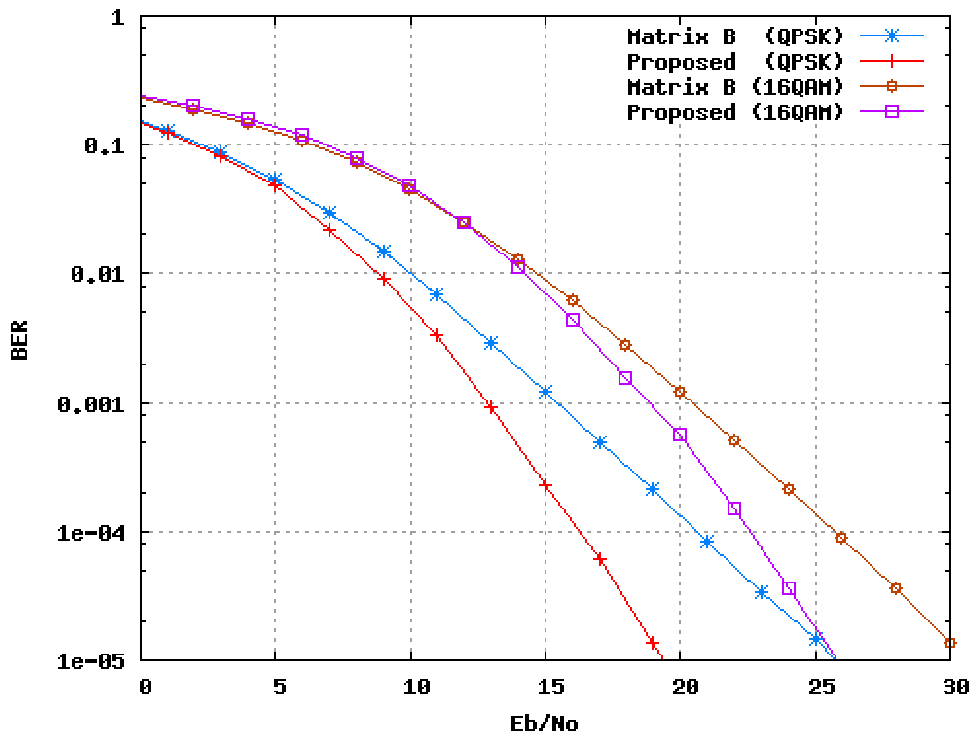

Fig. 1 Uncoded bit error rate performance comparison between the proposed code and the matrix B in a Rayleigh fading channel for QPSK modulation (2×2 MIMO system).

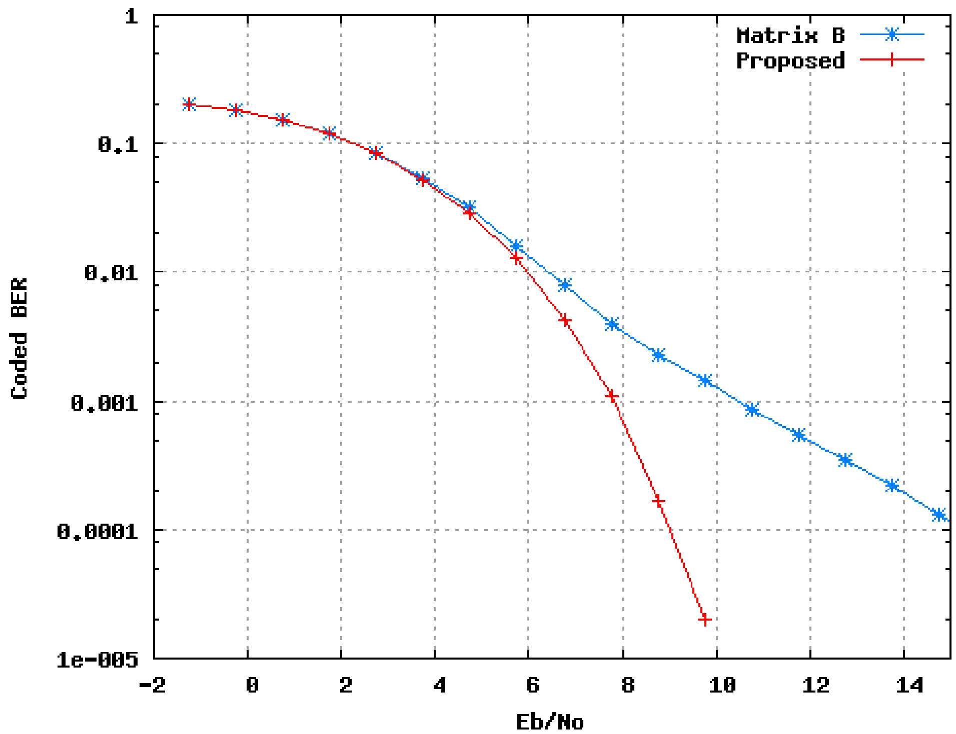

Fig. 2 Coded bit error rate performance comparison between the proposed code and the matrix B for band AMC mode with QPSK, 2/3 CTC, and channel normalization.

3.2 Comparison With Golden Code [2]

The Golden code [2] has been known to have the best performance (the greatest coding gain) among the full diversity space-time codes in public for rate 2 transmission with 2 transmit antennas. The minimum determinant of the proposed STC is evaluated to be the same as that of the Golden code. Furthermore, it is verified by computer simulations that the two STC's have the same bit error rate performance. One advantage of the proposed STC is that, for construction of linear STC, each symbol is multiplied by either a real number or a complex number with only imaginary part in the proposed STC, while it is multiplied by complex numbers consisting of both nonzero real and imaginary parts in the Golden code. So the number of multiplications required for STC encoding is smaller in the proposed STC than in the Golden code.

4 Specific Text Changes

[Change the paragraph in 8.4.8.3.3 at page 239 [1] as indicated]

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 ~~two~~ three transmission matrices shall be used:

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

$$B = \begin{bmatrix} S_i \\ S_{i+1} \end{bmatrix},$$

and

$$C = \frac{1}{\sqrt{1+r^2}} \begin{pmatrix} S_i + jr \cdot S_{i+3} & r \cdot S_{i+1} + S_{i+2} \\ S_{i+1} - r \cdot S_{i+2} & jr \cdot S_i + S_{i+3} \end{pmatrix}, \qquad r = \frac{-1+\sqrt{5}}{2},$$

where S_i and S_{i+1} in B may be encoded in different rates.

[Change Table 281a in 8.4.5.3.8 at page 165 as indicated]

Table 281a – MIMO DL basic IE format

Matrix_indicator	2	STC matrix (see 8.4.8.1.4)
		STC = STC mode indicated in the latest STC_Zone_IE().
		if (STC = 0b00) {
		00 = Matrix A
		01 = Matrix B
		10 = Matrix C
		~~10 ~ 11 = Reserved~~
		11 = Reserved
		}
		elseif (STC = 0b01) {
		00 = Matrix A
		01 = Matrix B
		10 = Matrix C
		11 = Reserved
		}
		elseif (STC = 10) {
		00 = Matrix A
		01 = Matrix B
		10 = Matrix C
		11 = Reserved
		}

[Change Table 282a in 8.4.5.3.9 at page 165 as indicated]

Table 282a – MIMO DL enhanced IE format

Matrix indicator	2	STC matrix (see 8.4.8.1.4)
		STC = STC mode indicated in the latest STC_Zone_IE().
		if (STC = 0b00) {
		00 = Matrix A
		01 = Matrix B
		10 = Matrix C
		~~10 ~ 11 = Reserved~~
		11 = Reserved
		}
		elseif (STC = 0b01) {
		00 = Matrix A
		01 = Matrix B
		10 = Matrix C
		11 = Reserved
		}
		elseif (STC = 10) {
		00 = Matrix A
		01 = Matrix B
		10 = Matrix C
		11 = Reserved
		}

[Change Table in 11.8.3.7.7 at page 294 as indicated]

OFDMA MSS demodulator for MIMO support

Type	Length	Value	Scope
155	1	~~Bit #0: 2 BS Tx Matrix A~~ ~~Bit #1: 2 BS Tx Matrix B~~ ~~Bit #2: 3 BS Tx Matrix A~~ ~~Bit #3: 3 BS Tx Matrix B~~ ~~Bit #4: 3 BS Tx Matrix C~~ ~~Bit #5: 4 BS Tx Matrix A~~ ~~Bit #6: 4 BS Tx Matrix B~~ ~~Bit #7: 4 BS Tx Matrix C~~ 0: 2 BS Tx Matrix A 1: 2 BS Tx Matrix B 2: 2 BS Tx Matrix C 3: 3 BS Tx Matrix A 4: 3 BS Tx Matrix B	SBC-REQ (see 6.3.2.3.23) SBC-RSP (see 6.3.2.3.24)

		5: 3 BS Tx Matrix C 6: 4 BS Tx Matrix A 7: 4 BS Tx Matrix B 8: 4 BS Tx Matrix C Values 9 ~ 255: Reserved	

5 Appendix – Derivation of the Proposed STC

Here it is briefly introduced how the proposed STC is derived. Derivation of the proposed STC is basically based on an exhaustive search. We start from the following general form of a linear space-time code

$$C = \begin{pmatrix} as_1 + bs_4 & es_2 + fs_3 \\ cs_2 + ds_3 & gs_1 + hs_4 \end{pmatrix}$$

where 8 complex weights i.e., *a, b,* ⋯ *,h* will be jointly optimized to maximize the minimum determinant of code error matrices. In order to ease an exhaustive search we use the following constraints. First the power constraints are as follows.

- Equality of total power per each transmitted symbol:

$$|a|^2 + |g|^2 = 1, \qquad |b|^2 + |h|^2 = 1$$
$$|c|^2 + |e|^2 = 1, \qquad |d|^2 + |f|^2 = 1$$

- Equality of power per each transmit antenna at each symbol time:

$$|a|^2 + |b|^2 = |c|^2 + |d|^2 = 1$$
$$|e|^2 + |f|^2 = |g|^2 + |h|^2 = 1$$

From those power constraints, we have 6 independent equations (other 2 equations can be induced from a linear combination of those 6 independent equations). For addressing the next constraints to be used, we rewrite the STC matrix C as the vector form by

$$\begin{bmatrix} \texttt{1st column of } C \\ \texttt{2nd column of } C \end{bmatrix} = \begin{pmatrix} a \\ 0 \\ 0 \\ g \end{pmatrix} s_1 + \begin{pmatrix} 0 \\ c \\ d \\ 0 \end{pmatrix} s_2 + \begin{pmatrix} 0 \\ e \\ f \\ 0 \end{pmatrix} s_3 + \begin{pmatrix} b \\ 0 \\ 0 \\ h \end{pmatrix} s_4 .$$

We constrain the four column vectors in the right side of the above equation to be orthogonal, that is,

$$ab^* + gh^* = 0$$
$$cd^* + ef^* = 0$$

which results in 2 complex value (4 real value) equations. Additionally, without loss of generality, we can fix the phase of one complex variable in each row of C to any value (e.g., arg(a)=arg(c)=0). At last, from the above three kinds of constraints, we have 12 real value equations in total. With them, the 8 complex (16 real) design variables can be expressed by 4 (=16-12) real variables as follows:

$$a=\frac{1}{\sqrt{1+r_1^2}},\quad b=\frac{jr_1e^{-j\frac{\phi_1}{2}}}{\sqrt{1+r_1^2}},\quad c=\frac{1}{\sqrt{1+r_2^2}},\quad d=\frac{jr_2e^{j\frac{\phi_2}{2}}}{\sqrt{1+r_2^2}},$$
$$e=\frac{jr_2e^{-j\frac{\phi_2}{2}}}{\sqrt{1+r_2^2}},\quad f=\frac{1}{\sqrt{1+r_2^2}},\quad g=\frac{jr_1e^{j\frac{\phi_1}{2}}}{\sqrt{1+r_1^2}},\quad h=\frac{1}{\sqrt{1+r_1^2}}.$$

From exhaustive searches over 4 real variables r_1, r_2, ϕ_1, and ϕ_2, we can find a lot of solutions of optimized variables among which are

$$r_1=\frac{-1+\sqrt{5}}{2}\ \textbf{ or }\ \frac{1+\sqrt{5}}{2},$$
$$r_2=\frac{-1+\sqrt{5}}{2}\ \textbf{ or }\ \frac{1+\sqrt{5}}{2},$$
$$\{\phi_1,\phi_2\}=\{0,\pi\}\ \textbf{ or }\ \{\pi,0\}.$$

One of the solutions, that is, $r_1=r_2=\frac{-1+\sqrt{5}}{2}$, $\phi_1=0$, and $\phi_1=\pi$, in the above is used for the proposed STC.

References

[1] IEEE P802.16e/D5, Draft IEEE Standard for Local and metropolitan area networks, Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems, Sep. 18, 2004.

[2] J.-C. Belfiore, G. Rekaya et E. Viterbo, "The Golden code: A 2x2 full-rate space-time code with non-vanishing determinants," *IEEE International Symposium on Information Theory*, p. 308, Chicago, USA, 2004.