Novel Approach for Eliminating BER Irreducible Floor in the Enhanced Blind Cyclic Detection for Space-Time Coding

Van-Su Pham, Minh-Tuan Le, Linh Mai, S.M. Humayun Kabir and Giwan Yoon*, **Member, KIMICS*

***Abstract*—In the blind Maximum-likelihood (ML) detection for Orthogonal Space-Time Block Codes (OSTBC), the problem of ambiguity in determining the symbols has been a great concern. A possible solution to this problem is to apply semi-blind ML detection, i.e. the blind ML decoding with pilot symbols or training sequence. In order to increase the performance, the number of pilot symbols or length of training sequence should be increased. Unfortunately, this leads to a significantly decrease in system spectral efficiency. This work presents an approach to resolve the aforementioned issue by introducing a new method for constructing transmitted information symbols, in which transmitting information symbols drawn form different modulation constellations. Therefore, the ambiguity can be easily eliminated. In addition, computer simulation is implemented to verify the performance of the proposed approach.

***Index Terms*—Blind Detection, Ambiguity Elimination, Orthogonal Space-Time Block Code.

I. INTRODUCTION

RECENTLY Orthogonal Space-Time Codes [1]-[3], approaches to exploit diversity gain in Multiple-Input Multiple-Output (MIMO) system, have been an attractive research topic for enhancing system performance and coping with the requirement of next generation wireless communication systems. With orthogonal property, OSTBCs not only provide full diversity but also allow simple maximum-likelihood decoding algorithm when channel state information (CSI) is perfectly known to the receiver. Practically, CSI can be obtained at the receiver via training signals. In order to achieve sufficient accuracy, however, a long training period may be required. Consequently, a noticeable reduction in data rate can be observed, especially in fast and relative fast fading channel.

The significant decrease in spectral efficiency resulted by long training sequence can be minimized by employing blind and semi-blind detection methods [4]-[6]. Unfortunately, in the blind ML detections, the problem of ambiguity in determining the symbols has been a serious concern [4]-[7]. This issue has been tackled with the application of semi-blind ML, i.e. the blind ML decoder exploiting pilot symbols or training sequence. In these solutions, however, in order to increase the performance the number of pilot symbols or the length of training sequence should be increased. As a result, the system spectral efficiency degraded dramatically.

This work presents an approach to resolve the aforementioned problem by introducing a new method for the construction of transmitted information symbols, which are drawn from different orthogonal constellations. With the independent and orthogonal set of transmitted symbols, the ambiguity can be easily eliminated.

The remaining of this paper is organized as follows. System model is presented in section II. Section III gives detail of the proposed method. The computer simulation result is illustrated in section IV to verify the proposed decoder. Finally, conclusion of our work is given in section V.

II. SYSTEM MODEL

Let us consider a multiple antenna system with n_T transmit and n_R receive antennas, referred to as (n_T , n_R) system. $C(p)$ denotes the p^{th} OSTBC codeword that resulted from mapping information symbol vector $\mathbf{s}_p=[s_{p,1} \;\; s_{p,2} \;\; \cdots \;\; s_{p,K}]^T$, whose entries are drawn from some complex M-PSK constellation $\mathbf{\Omega}$ (M=2,4,8,...), into a code matrix with code length of L. Then, an OSTBC can be expressed as:

$$\mathbf{C}(\mathbf{s}_p)=\sum_{k=1}^{K}(\mathbf{A}_k\Re\{s_{p,k}\}+j\mathbf{B}_k\Im\{s_{p,k}\}) \qquad (1)$$

where $\Re\{.\}$ and $\Im\{.\}$ respectively denote the real and imaginary parts, $j=\sqrt{-1}$. $\mathbf{A}_k$ and $\mathbf{B}_k$ are $n_T \times L$ real-valued dispersion matrices satisfying the following conditions [6]:

Manuscript received February 6, 2008; revised May 2, 2008. This work was supported by the ERC program of MOST/KOSEF (Intelligent Radio Engineering Center)

The authors are with the School of Engineering, Information and Communications University (ICU), Daejeon, 305-732, Korea (Tel: +82-42-866-6201, Email: {vansu_pham,gwyoon}@icu.ac.kr)

$$\begin{cases} \mathbf{A}_k\mathbf{A}_k^H = \mathbf{B}_k\mathbf{B}_k^H = \mathbf{I}_{n_T} \\ \mathbf{A}_k\mathbf{A}_n^H = -\mathbf{A}_n\mathbf{A}_k^H \, (k \neq n) \\ \mathbf{B}_k\mathbf{B}_n^H = -\mathbf{B}_n\mathbf{B}_k^H \, (k \neq n) \\ \mathbf{A}_k\mathbf{B}_n^H = \mathbf{B}_n\mathbf{A}_n^H \end{cases} \qquad (2)$$

The OSTBC given in (1) has the orthogonal property, which can be represented as:

$$\mathbf{C}(\mathbf{s}_p)\mathbf{C}^H(\mathbf{s}_p) = \| \mathbf{s}_p \|_2^2 \, \mathbf{I}_{n_T} \qquad (3)$$

where $\| . \|_2$ denotes the 2-norm.

At the receiver, the received signal corresponding to the p^{th} transmitted code block, p=1, 2,...Q, is given as:

$$\mathbf{Y}_p = \mathbf{H}\mathbf{C}\left(\mathbf{s}_p\right) + \mathbf{W}_p \qquad (4)$$

where $\mathbf{H}$ is an $n_R \times n_T$ channel matrix, $\mathbf{W}_p$ is an $n_R \times L$ additive white Gaussian noise (AWGN) matrix with covariance matrix $E\{\mathbf{W}_p\mathbf{W}_p^H\} = \sigma^2\mathbf{I}_{n_R}$.

In case the CSI is perfectly known at the receiver, the ML detection of $\mathbf{s}_p$ is given by:

$$\begin{aligned} \hat{\mathbf{s}} &= \arg\min_{\mathbf{s}_p \in \mathbf{\Omega}} \| \mathbf{Y} - \mathbf{H}\mathbf{C}(\mathbf{s}_p) \|_2^2 \\ &= \arg\min_{\mathbf{s}_p \in \mathbf{\Omega}} \sum_{k=1}^{K} \| s_{p,k} - \tilde{s}_{p,k} \|^2 \end{aligned} \qquad (5)$$

In (5), the decision statistic of transmitted symbol $s_{p,k}$ is computed as:

$$\tilde{s}_{p,k} = \frac{\Re\{Tr\{\mathbf{Y}^H\mathbf{H}\mathbf{A}_k\}\} - j\Im\{Tr\{\mathbf{Y}^H\mathbf{H}\mathbf{B}_k\}\}}{\| \mathbf{H} \|_2^2} \qquad (6)$$

where $Tr\{.\}$ is the trace operation.

It can be seen that (5) can be decoupled into K terms, where each term depends on exactly one complex symbol. Consequently, the detection of $s_{p,k}$ simply becomes:

$$\hat{s}_{p,k} = \arg\min_{s_{p,k} \in \mathbf{\Omega}} (s_{p,k} - \tilde{s}_{p,k})^2 \qquad (7)$$

In case CSI is not available at the receiver, the blind ML detector is given by [4]:

$$\hat{\mathbf{s}} = \arg\min_{\mathbf{H}, \mathbf{s}_p \in \mathbf{\Omega}} \sum_{p=1}^{Q} \| \mathbf{Y}_p - \mathbf{H}\mathbf{C}(\mathbf{s}_p) \|_2^2 \qquad (8)$$

III. PROPOSED APPROACH

In this section, we first briefly summarize the cyclic ML for blind detection, which is used as a realization of (8), for complete viewpoint. Let us define:

$$\begin{aligned} &\mathbf{h} = vec(\mathbf{H}) \\ &\mathbf{s}' = [\Re\{\mathbf{s}_1\}^T \ \cdots \ \Re\{\mathbf{s}_Q\}^T \ \ \Im\{\mathbf{s}_1\}^T \ \cdots \ \Im\{\mathbf{s}_Q\}^T]^T \\ &\mathbf{F}_p^{(a)} = [vec(\mathbf{Y}_p\mathbf{A}_1^H) \ \cdots \ vec(\mathbf{Y}_p\mathbf{A}_K^H)] \\ &\mathbf{F}_p^{(b)} = [-j * vec(\mathbf{Y}_p\mathbf{B}_1^H) \ \cdots \ -j * vec(\mathbf{Y}_p\mathbf{B}_K^H)] \\ &\mathbf{F} = [\mathbf{F}_1^{(a)} \ \cdots \ \mathbf{F}_Q^{(a)} \ \ \mathbf{F}_1^{(b)} \ \cdots \ \mathbf{F}_Q^{(b)}] \end{aligned}$$

We can re-express (8) as:

$$\hat{\mathbf{s}} = \arg\min_{\mathbf{h}, \mathbf{s} \in \mathbf{\Omega}} \| \mathbf{F} - \mathbf{h}\mathbf{s}' \|_2^2 \qquad (9)$$

The minimization problem in (9) implies that it must be minimized jointly with respect to $\mathbf{h}$ and $\mathbf{s}'$. Neglecting the constraint that $\mathbf{s}'$ belongs to a finite alphabet, the minimum is achieved when $\mathbf{h}$ and $\mathbf{s}'$ are respectively equal to left and right singular vectors of $\mathbf{F}$. Mathematically, we have:

$$\tilde{\mathbf{h}}\tilde{\mathbf{s}}'^T = \lambda_1 \mathbf{u}_1 \mathbf{v}_1 \qquad (10)$$

Where λ_1 is the largest singular value of $\mathbf{F}$, $\mathbf{u}_1$ and $\mathbf{v}_1$ are the associated left and right singular vectors. Based on (10), the initial estimate of $\mathbf{h}$ and thus $\mathbf{H}$ can be achieved. From that, the blind cyclic ML detector is given as follows:

Initialization: *Compute an initial estimate of* $\mathbf{H}$, *i.e.* $\hat{\mathbf{H}}$, *based on (10).*

Iteration:

1. *Use the latest estimate of* $\mathbf{H}$ *in (7) to detect each transmitted symbols. After this step, we obtain* $\hat{\mathbf{s}}_p$.
2. *Using the orthogonal property of OSTBCs in (3), the channel is re-estimated as:*

$$H = \frac{\sum_{p=1}^{Q} \mathbf{Y}_p \mathbf{C}^H(\hat{\mathbf{s}}_p)}{\sum_{p=1}^{Q} \| \hat{\mathbf{s}}_p \|_2^2}$$

3. *Iterate until convergence or until a given number of iterations has been carried out.*

In this work, we consider the ambiguity in detection of (8) or (9) in case there is no pilot signal. We can see that $\{\mathbf{H}, \mathbf{s}\}$ is the unique ML solution if and only if we cannot find another solution, denoted by $\{\tilde{\mathbf{H}}, \tilde{\mathbf{s}}\}$, such that:

$$\mathbf{H}\mathbf{C}(\mathbf{s}_p) = \tilde{\mathbf{H}}\mathbf{C}(\tilde{\mathbf{s}}_p) \ \text{(p=1,2,..)} \qquad (11)$$

One solution with the aid of antenna array is given in [8]. Herein, we see that, if the searching set $\mathbf{\Omega}$ does not contain any vector $\mathbf{s}'$ such that $\mathbf{s}' = k\mathbf{s}$, for any $k \neq 0$, we can avoid the ambiguity. Thus, we proposed a new approach to construct $\mathbf{\Omega}$ satisfying that there does not exist $\mathbf{s}' = k\mathbf{s}$ for any $k \neq 0$. The new set of $\mathbf{\Omega}$ is constructed as follows. In OSTBC with n_T transmit antennas transmitting n symbols, the first $n-1$ symbols are directly mapped, while the last one is differentially mapped based on the remaining bit(s) and the mapped information bit(s) of $n-1$ precede symbols. For sake of clarity of the explanation, let us assume that we construct the transmitted symbol set for OSTBC Alamouti of (2,2) system using BPSK and 8-PSK modulation constellations. In stead of independently mapping two information bits on BPSK, we use three information bits. The first information bit is directly mapped into BPSK constellation to get symbol $\mathbf{s}_1$, then the information of this bit together with the remaining two bits are differential mapped into 8-PSK constellation to get symbol $\mathbf{s}_2$, and $\mathbf{s} = [\mathbf{s}_1 \quad \mathbf{s}_2]^T$. It is worth noting that, herein, we use differential mapping, not direct mapping, therefore, it always guarantees that there does not exist $\mathbf{s}' = k\mathbf{s}$ for any $k \neq 0$.

IV. COMPUTER SIMULATION RESULT

In order to evaluate the performance of the proposed decoder, we implement computer simulation for (3,3) system employing complex-valued rate ¾ OSTBC [9]. The modulation schemes are BPSK and 8-PSK. The first two symbols are resulted from the directly mapping of two information bits to the BPSK, the last one resulted from differential mapping the fist two information bits and the last bit. The frame length is set to 48. The channel is assumed to remain constant within each frame, and randomly changes from one frame to the next. The channel gains are randomly generated and assumed to be i.i.d. zero-mean complex Gaussian distribution with variance 0.5 per dimension.

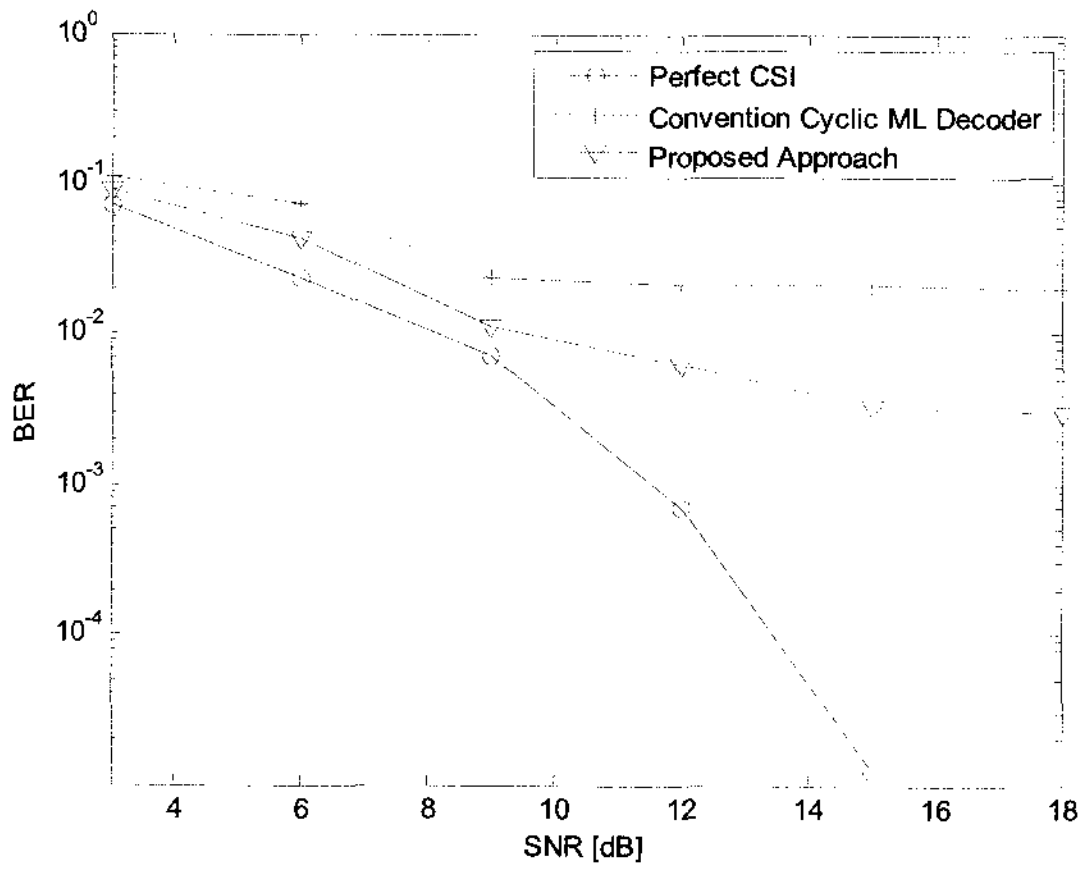


Fig. 1 BER performance of the proposed decoder with (3,3) system employing complex-valued code rate ¾ OSTBC.

As can be seen from Fig.1, although the proposed method also suffers from irreducible error floor, it can improve BER performance much better than the conventional blind ML detection.

IV. CONCLUSIONS

In this work, a novel approach for constructing the transmitted symbol set to eliminate the ambiguity in blind ML detection has been proposed. In the proposed approach, we differentially map input information bits into different modulation constellations, leading to the separable independent and orthogonal transmitted symbol set. Therefore, the pilot signals or training sequence can be reduced or eliminated. Consequently, the reduction in spectral efficiency is lightened, while the irreducible error floor is lowed remarkably.

ACKNOWLEDGMENT

This work was supported by the ERC program of MOST/KOSEF (Intelligent Radio Engineering Center).

REFERENCES

[1] S.M. Alamouti, "*A Simple transmit diversity technique for wireless communications*", IEEE J. Sel. Areas Comm., Vol.16, No.8, Oct.1998, pp.1451-1458.

[2] V. Tarokh, H. Jafarkhani and A.R. Calderbank, "*Space-time block codes from orthogonal designs*", IEEE Trans. Inform. Theory, Vol.45, No.5, Jul. 1999, pp.1456-1467.

[3] P. Stoica and G. Ganesan, "*Space-time block codes: A maximum SNR approach*", IEEE Trans. Inform. Theory, Vol.47, No.4, May 2001, pp.1650-1656.

[4] P. Stoica and Ganesan, "*Space-time block codes: trained, blind and semi-blind detection*", Digital Signal Processing, Vol.13, 2003, pp.93-105.

[5] E.G. Larsson, P. Stoica and J. Li, "*Orthogonal space-time block codes: maximum likelihood detection for unknown channels and unstructured interferences*", IEEE Trans. Sign. Proc., Vol.51, No.2, Feb. 2003, pp.362-372.

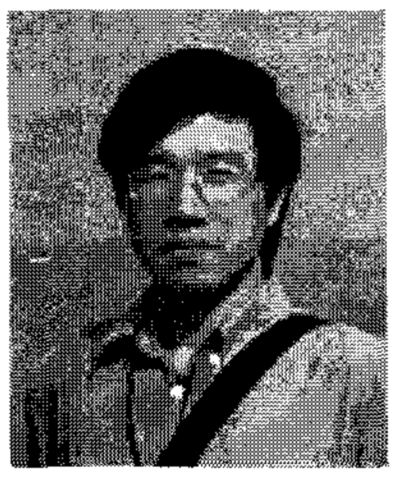
[6] Minh-Tuan Le, Van-Su Pham, Linh Mai and Giwan Yoon, "", Journal of KIMICS, Vol.4, No.4, Dec. 2006, pp.136-140.

[7] Wing-Kin Ma, P.C. Ching, T.N. Davidson and B.-N. Vo, "*Blind Symbol Identifiability of Orthogonal Space-time Block Codes*", IEEE ICASSP 2004 Proc., Vol. 4, May 17-21, 2004, pp.821-824.

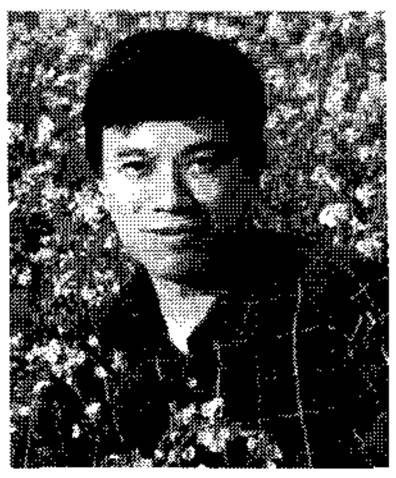
[8] Shilpa Talwa, Mats Viberg and Arogyaswami, "*Blind Separation of Synchronous Co-Channel Digital Signals Using an Antenna Array – Part I: Algorithms*", IEEE Trans. Sign. Proc., Vol.44, No.5, May 1996, pp.1184-1197.

[9] B. Vucetic and J. Yuan, *Space-Time Coding*, Wiley, 2003.

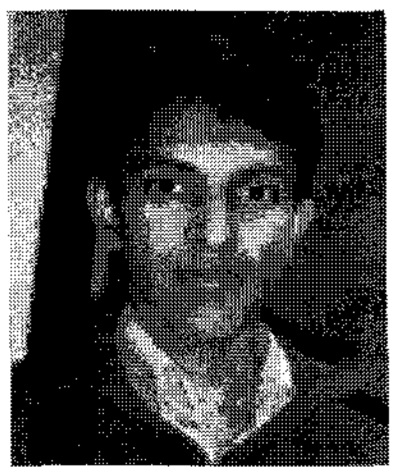
Van-Su Pham
Member KIMICS. Received B.S. degree in Electronic Engineering, Hanoi University of Technology, Vietnam, in 1999. Received M.S. degree in Electrical Engineering, Information and Communications University (ICU), Taejon, Korea in 2003. Since Feb. 2004, he has been a Ph.D. student in Communication Electronics Lab, Information and Communications University (ICU), Daejeon, Korea. The research areas of interest include intelligent algorithms, space-time coding and MIMO systems.



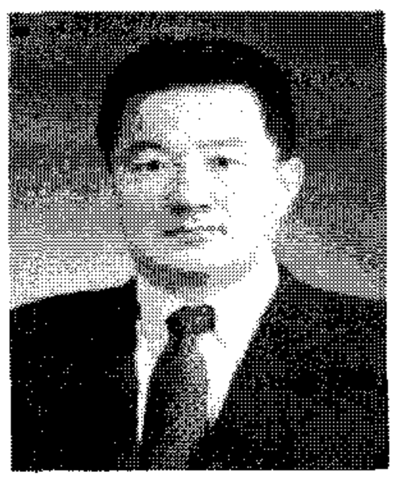
Minh-Tuan Le
Received his B.S. degree in Electronics and Telecommunication from Hanoi University of Technology, Vietnam in 1999, M.S. and Ph.D. degree in Electrical Engineering from Information and Communications University (ICU), Daejeon, Korea in 2003, and 2006. From 1999 to summer 2001, he was lecturer of Posts and Telecommunications Institute of Technology, Vietnam. His research interest includes Smart Antenna, Space-Time Coding and MIMO Systems.



Linh Mai
Member KIMICS Received B. S. degree in Natural Science, Hanoi University, Vietnam, in 1996. M.S. Degree in ITIMS, Hanoi, Vietnam, in 1998. From 1998 to summer 2001, he was teacher of Posts and Telecommunications Institute of Technology, Vietnam. Since 2001 to now, he has been Ph.D. student in Communication and Electronics Lab, Information & Communications University (ICU), Daejeon, Korea.



S. M. Humayun Kabir
Member KIMICS. Received B.S. degree in Computer Science and Engineering, Khulna University, Bangladesh, in 2007. Since then, he has been an M.S. student in Communication Electronics Lab, Information and Communications University (ICU), Daejeon, Korea. The research areas of interest include intelligent algorithms, space-time coding and MIMO systems.



Giwan Yoon
Member KIMICS. Received B.S. degree in Seoul National University (SNU), in 1983 and M.S. degree in KAIST, in 1985, both Seoul, Korea. Received Ph.D. degree in The University of Texas at Austin, in 1994, Texas, USA. From 1985 to 1990, he was with LG Group, Seoul, Korea. From 1994 to 1997, he was with digital equipment corporation, MA, USA. Currently, he is a professor of school of engineering, Information and Communications University (ICU), Daejeon, Korea. His major research areas of interest include multifunctional intelligent devices & their technologies for RF and wireless applications.