Efficient Training Sequence Structure for Adaptive Linear Multiuser Detectors in Space-Time Block Coded Multiuser Systems

Hyeon Chyeol Hwang*, Seung Hoon Shin**, Hyun Taek Seok***, Hyung Ki Lee****, Dong Kwan Yoo*****, Kyung Sup Kwak****** *Regular Members*

ABSTRACT

In this letter, we propose an efficient training sequence structure for adaptive linear multiuser detectors in space-time block coded multiuser systems, by exploiting a particular property of the minimum mean square error multiuser detectors used in these systems. The proposed structure wastes less overall system capacity than the straightforward training structure, without any corresponding loss of performance, as confirmed by the simulation results.

Key Words : multiuser systems, multiple antenna systems, space-time block code, adaptive implementation, multiuser detector.

Ⅰ. Introduction

Increasing system capacity without requiring additional bandwidth is of major significance for spectrally-efficient high-rate wireless communication systems. Space-Time block codes(STBCs) help increase reliability over wireless networks [1], and they can achieve full diversity gains with simple linear processing at the receiver. It was shown in[2] that K co-channel users, each equipped with N transmit antennas and transmitting uncorrelated signals, can be detected with N-order diversity gains if the receiver is equipped with $N(K-1)+1$ antennas. However, the structure of the STBC can be exploited to reduce the number of receive antennas. It was shown in [2] that only K receive antennas are needed to provide N order diversity gains and suppress signals from $(K-1)$ co-channel users.

A simple interference cancellation scheme for two co-channel users employing Alamouti's STBC scheme[3] was previously reported in [2]. With this scheme, by using two transmit antennas for each user and two receive antennas at the base station, it is possible to double the system capacity by applying only linear processing at the receiver[2]. This scheme was extended to the case of multiple users equipped with more than two transmit antennas in [4], where it was shown that the system capacity can be further increased by allowing for more co-channel users. The effectiveness of the minimum mean square error (MMSE) interference

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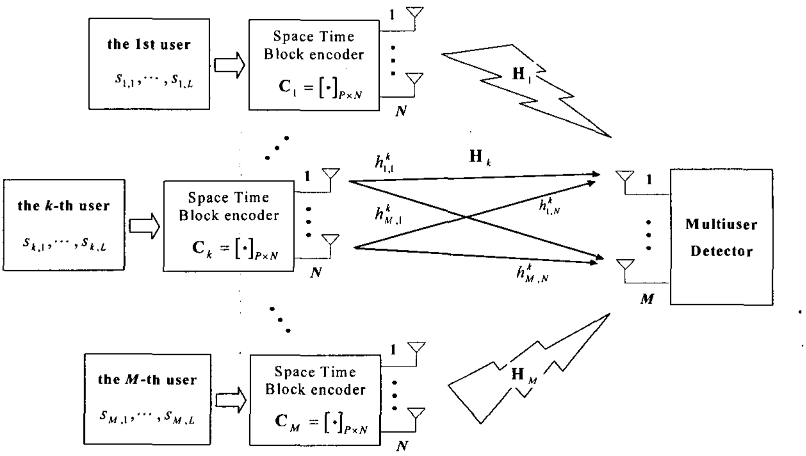

Fig. 1. Mutiuser systems with M co-channel users using space time block codes

cancellation technique for the STBC *multiuser* systems described in [2] relies on the accuracy of the channel estimation available at the receiver. An interference cancellation scheme based on the recursive least squares algorithm(RLS) for STBC multiuser systems is presented in [5]. In contrast to the MMSE detector, this scheme does not require any explicit knowledge of the channel and the interferences, and its complexity is less than that of the MMSE technique. However, it requires a long training period for the weight vector coefficients to converge in an environment consisting of many co-channel users.

In this paper, the training sequences for the adaptive linear multiuser detectors used in STBC multiuser systems, such as those using the least mean squares (LMS) and RLS algorithms[6], are considered. We show the specific algebraic property of the MMSE detector for multiusers employing three or four transmit antennas while the property in two transmit antennas is inferred from the previous work of STBC spatial multiplexing system[7]. By exploiting the property, an efficient training sequence structure is designed, in order to reduce the system overhead, without any corresponding loss of performance. The RLS adaptation is considered for the evaluation of the bit error rate(BER) performance. The simulation results show the applicability of the proposed scheme to the adaptive linear implementation.

This paper is organized as follows. In section II, we introduce the system and channel model. In section III, we review MMSE multiuser detectors and their properties. In section IV, an efficient training sequence structure is described. Simulation results are provided in section V, followed by our conclusions in section VI.

Notation: All boldface letters indicate vectors (lower case) or matrices (upper case). X^T and X^H indicate the transpose and the conjugate transpose operation, respectively. X^* denotes the complex conjugate, and X^{-1} denotes matrix inverse. $(X)_{i,j}$ denotes the (i,j)-th element of matrix X, and $(X)_i$ represents the i-th row vector of matrix or the i-th element of vector.

Ⅱ. System Model

We consider a multiuser system with M synchronous co-channel users, in which each user is equipped with N transmit antennas as depicted in Fig.1. In addition, a receiver is equipped with M receive antennas, in order to suppress the interference from the co-channel users, without sacrificing the diversity order afforded by the STBCs. It was shown in [1] that only M antennas are required at the receiver to suppress the interference from the $(M-1)$ co-channel STBC users. A STBC matrix, C_k for the k-th user is defined by a $P\times M$ matrix over P symbol times[8]. The entries of C_k are linear combinations of the transmission symbols, $s_{k,l}$ and their conjugate where $l=1,\cdots,L$. The rate, R of the code is defined as $R=L/P$. In this paper, the rate one code proposed in [3] for $N=2$ and the rate half codes proposed in [8] for $N=3$ and 4 are considered. The STBC matrices for $N=2,3,4$ are given in order by [8]

$$C_k=\begin{bmatrix} s_{k,1} & s_{k,2} \\ -s_{k,2}^* & s_{k,1}^* \end{bmatrix},$$

$$C_k=\begin{bmatrix} s_{k,1} & s_{k,2} & s_{k,3} \\ -s_{k,2} & s_{k,1} & -s_{k,4} \\ -s_{k,3} & s_{k,4} & s_{k,1} \\ -s_{k,4} & -s_{k,3} & s_{k,1} \\ s_{k,1}^* & s_{k,2}^* & s_{k,3}^* \\ -s_{k,2}^* & s_{k,1}^* & -s_{k,4}^* \\ -s_{k,3}^* & s_{k,4}^* & s_{k,1}^* \\ -s_{k,4}^* & -s_{k,3}^* & s_{k,2}^* \end{bmatrix}, \text{ and} \tag{1}$$

$$C_k=\begin{bmatrix} s_{k,1} & s_{k,2} & s_{k,3} & s_{k,4} \\ -s_{k,2} & s_{k,1} & -s_{k,4} & s_{k,3} \\ -s_{k,3} & s_{k,4} & s_{k,1} & -s_{k,2} \\ -s_{k,4} & -s_{k,3} & s_{k,1} & s_{k,1} \\ s_{k,1}^* & s_{k,2}^* & s_{k,3}^* & s_{k,4}^* \\ -s_{k,2}^* & s_{k,1}^* & -s_{k,4}^* & s_{k,3}^* \\ -s_{k,3}^* & s_{k,4}^* & s_{k,1}^* & -s_{k,2}^* \\ -s_{k,4}^* & -s_{k,3}^* & s_{k,2}^* & s_{k,1}^* \end{bmatrix}.$$

We assume that the channel is quasi-static flat-fading, i.e., constant over a frame as in [1, 4, 5]. Let H_k denote the $M\times N$ channel matrix for the k-th user. The (n,m)-th element, $h_{n,m}^k$ of H_k is the fading path gain between transmit antenna m and receive antenna n. The fading path gains are modeled as independent and identical distribution (i.i.d.) complex gaussian random variables with zero mean and unit variance[1, 4, 5]. H_k can be expressed as a collection of N transmit vectors, $H_k=[h_{k,1}\ \cdots h_{k,N}]$ where $h_{k,i}$ is the $M\times 1$ column vector. The received signal over P symbol times is

$$\begin{aligned} R &= \sum_{k=1}^{M}\sqrt{E_k/N}H_kC_k^T+N \\ &\equiv HAC+N\equiv\left[r_1\ \cdots\ r_P\right] \end{aligned} \tag{2}$$

where R and N are $M\times P$ received signal and noise matrices, respectively, and r_i is the $M\times 1$ column vector. The $MN\times P$ stacked STBC block is defined as $C=[C_1\cdots C_M]^T$, and the $M\times MN$ stacked channel matrix is defined as $H=[H_1\cdots H_M]$. Normalization is imposed such that the mean total power transmitted on N transmit antennas for the k-th user is E_k, and then

$$A=diag\left(\sqrt{E_1/N}I_N,\ \cdots,\ \sqrt{E_M/N}I_N\right).$$

The entries for N are i.i.d. complex gaussian random variables with zero mean and σ_n^2 variance. In the case of the modified model of (1), we stack the column vectors and rewrite this as

$$\bar{r}=\left[r_1^T\cdots r_{P/2}^T r_{P/2+1}^H\cdots r_P^H\right]=\bar{H}\bar{A}s+\bar{n}, \tag{3}$$

where $\bar{r}$ and $\bar{n}$ are the $PM\times 1$ vectors

$$\bar{A}=diag\left(\sqrt{E_1/N}I_L,\ \cdots,\ \sqrt{E_M/N}I_L\right).$$

The symbol vector transmitted by M users is $s=[s_1^T s_2^T\cdots s_M^T]^T$, where $s_k=[s_{k,1}s_{k,2}\cdots\ s_{k,L}]^T$ for the k-th user. The entries of $\bar{n}$ are also i.i.d. with $\bar{n}\sim CN(0,\sigma_n^2)$. The coded channel matrix, $\bar{H}=[\bar{H}_1\cdots\bar{H}_M]$, is given by equation (4) for $N=2$

$$\bar{H}_k=\begin{bmatrix} h_{k,1} & h_{k,2} \\ h_{k,2}^* & -h_{k,1}^* \end{bmatrix} \tag{4}$$

and as follows for $N=3$ and 4, respectively

$$\bar{H}_k=\begin{bmatrix} h_{k,1} & h_{k,2} & h_{k,3} & 0 \\ h_{k,2} & -h_{k,1} & 0 & -h_{k,3} \\ h_{k,3} & 0 & -h_{k,1} & h_{k,2} \\ 0 & h_{k,3} & -h_{k,2} & -h_{k,1} \\ h_{k,1}^* & h_{k,2}^* & h_{k,3}^* & 0 \\ h_{k,2}^* & -h_{k,1}^* & 0 & -h_{k,3}^* \\ h_{k,3}^* & 0 & -h_{k,1}^* & h_{k,2}^* \\ 0 & h_{k,3}^* & -h_{k,2}^* & -h_{k,1}^* \end{bmatrix}$$

and

$$\bar{\boldsymbol{H}}_k = \begin{bmatrix} \boldsymbol{h}_{k,1} & \boldsymbol{h}_{k,2} & \boldsymbol{h}_{k,3} & \boldsymbol{h}_{k,4} \\ \boldsymbol{h}_{k,2} & -\boldsymbol{h}_{k,1} & \boldsymbol{h}_{k,4} & -\boldsymbol{h}_{k,3} \\ \boldsymbol{h}_{k,3} & -\boldsymbol{h}_{k,4} & -\boldsymbol{h}_{k,1} & \boldsymbol{h}_{k,2} \\ \boldsymbol{h}_{k,4} & \boldsymbol{h}_{k,3} & -\boldsymbol{h}_{k,2} & -\boldsymbol{h}_{k,1} \\ \boldsymbol{h}^*_{k,1} & \boldsymbol{h}^*_{k,2} & \boldsymbol{h}^*_{k,3} & \boldsymbol{h}^*_{k,4} \\ \boldsymbol{h}^*_{k,2} & -\boldsymbol{h}^*_{k,1} & \boldsymbol{h}^*_{k,4} & -\boldsymbol{h}^*_{k,3} \\ \boldsymbol{h}^*_{k,3} & -\boldsymbol{h}^*_{k,4} & -\boldsymbol{h}^*_{k,1} & \boldsymbol{h}^*_{k,2} \\ \boldsymbol{h}^*_{k,4} & \boldsymbol{h}^*_{k,3} & -\boldsymbol{h}^*_{k,2} & -\boldsymbol{h}^*_{k,1} \end{bmatrix}. \quad (5)$$

Ⅲ. Efficient Adaptive MMSE Multiuser Detectors

A zero forcing (ZF) detector completely eliminates multiuser interference (MUI) and inter-symbol interference (ISI) at the expense of noise enhancement. An MMSE receiver balances MUI/ISI mitigation with noise enhancement and minimizes the mean square error (MSE) [9]. The MMSE filters are given by the following expression [6, 9]

$$G = arg\min_{\tilde{G}} E\{\|\tilde{G}\bar{r} - s\|_F^2\}. \quad (6)$$

where $\|\cdot\|_F^2$ denotes the squared Frobenius norm of a matrix. Utilizing the orthogonality principle, G is easily derived as follows [6, 9]

$$G = \left(\bar{A}\,\bar{H}^H\bar{H}\bar{A} + \sigma_n^2 I_{LM}\right)^{-1}\bar{A}\,\bar{H}^H. \quad (7)$$

The estimate of s_k for the k-th user, $\hat{s}_k = [\hat{s}_{k,1} \cdots \hat{s}_{k,L}]^T$ is given by

$$\hat{s}_k = \dot{G}_k\bar{r} \quad (8)$$

where $\dot{G}_k$ is the $L \times PM$ MMSE filter matrix which consists of the $(Lk-L+1)$-th row to Lk-th row of G and decodes L symbols within C_k. The MSE for $s_{k,l}$ is given by [10]

$$\begin{aligned} J_{\min}^{k,l} &= E\{|\hat{s}_{k,l} - s_{k,l}|^2\} \\ &= \left[\left(\frac{1}{\sigma_n^2}\bar{A}\,\bar{H}^H\bar{H}\bar{A} + I_{4M}\right)\right] \end{aligned} \quad (9)$$

We proved the specific algebraic property of an MMSE detector in alamouti's STBC multiplexing systems [7]. The property can be exploited efficiently in multiuser systems where each user employs the two transmit antennas. In the case of co-channel users with three and four transmit antennas, the property given by Eq. (10) and (11) can also be shown by investigating Eq. (7) and using block matrix inversion.

Equation (7) requires knowledge of the transmission power of all of the users and channels, as well as the noise variance. Thus, it appears to suffer from the problem of requiring a large amount of assumed knowledge, as is the case in many multiuser receivers[6]. Repeated matrix inversions would be necessary if the channel was nonstationary, so this technique would also be computationally expensive. However, the adaptive implementation of MMSE detectors[11] may solve the problems of excessive assumed knowledge and complexity simultaneously.

It is well known [10] that the MMSE filter can be approximated adaptively by many algorithms. Property 1 suggests that only one adaptive filter may be calculated and updated for the desired

Property 1 : Let the linear filters decoding the first symbol of the k-th user be

$$(G)_{2(k-1)+1} = [g_{k,1}\, g_{k,2}], \qquad \text{for } N=2,$$
$$(G)_{4(k-1)+1} = [g_{k,1}\, g_{k,2}\, g_{k,3}\, g_{k,4}\, g_{k,5}\, g_{k,6}\, g_{k,7}\, g_{k,8}], \qquad \text{for } N=3 \text{ and } 4, \quad (10)$$

where $g_{k,j}$ are the $M \times 1$ row vectors. Then, the filter decoding the other symbols of the k-th user is given by

$$(G)_{2(k-1)+2} = [g^*_{k,2}\, -g^*_{k,1}], \qquad \text{for } N=2,$$
$$\left\{\begin{array}{l} (G)_{4(k-1)+2} = [g_{k,2}\, -g_{k,1}\, -g_{k,4}\, g_{k,3}\, g_{k,6}\, -g_{k,5}\, -g_{k,8}\, g_{k,7}] \\ (G)_{4(k-1)+3} = [g_{k,3}\, g_{k,4}\, -g_{k,1}\, -g_{k,2}\, g_{k,7}\, g_{k,8}\, -g_{k,5}\, g_{k,6}] \\ (G)_{4(k-1)+4} = [g_{k,4}\, -g_{k,3}\, g_{k,2}\, -g_{k,1}\, g_{k,8}\, -g_{k,7}\, g_{k,6}\, -g_{k,5}] \end{array}\right., \qquad \text{for } N=3 \text{ and } 4. \quad (11)$$

user. The other $(L-1)$ filters decoding the other $(L-1)$ symbols are easily derived from Property 1, which results in a reduction in both the receiver complexity and the memory requirements. We apply Property 1 to the RLS algorithm and summarize this process in Table 1. Let $w_{k,1}$ be the weight vector decoding the first symbol of the k-th user. The weight vectors decoding the other $(L-1)$ symbols, $w_{k,2}, \cdots, w_{k,L}$ are derived directly from $w_{k,1}$ by using Property 1.

Ⅳ. An efficient Training Sequence Structure

Training sequences, which are used to train the weight vectors, cause the system overhead. Property 1 suggests that one distinct training symbol needs to be placed in one STBC matrix, while the other symbols in matrix can be used as data symbols. Figure 2 shows the proposed training sequence structure for the k-th user using 2×2 and 4×8 STBCs. The structure for a 3×8 STBC is not included, but it can easily be plotted using that of the 4×8 STBC. $d_k(n)$ and $s_{k,l}(n)$ denote the training symbols known at the k-th user and the unknown data symbols of the n-th STBC matrix during the training periods, respectively. In this scheme, to decode the data symbols $s_{k,l}(n)$ included in the training periods, the received signals during the training periods should be stored in buffer. After the weight vector has converged, the buffered signals are processed to estimate $s_{k,l}(n)$.

Table 1. The adaptation of the weight vectors required to decode the L symbols of the k-th user

(1)	$w_{k,1}(0)=0,\ k(0)=0,\ R^{-1}=\delta I_{LM\times LM}$
(2)	for $n=1,\cdots,loop$
(3)	$\hat{d}_k(n)=w_{k,1}^H(n-1)\bar{r}(n)$
(4)	$e_{k,1}(n)=d_k(n)-\hat{d}_k(n)$
(5)	$k(n)=\dfrac{R^{-1}(n-1)\bar{r}(n)}{\lambda+\bar{r}^H(n)R^{-1}(n-1)\bar{r}(n)}$
(6)	$R^{-1}(n)=[R^{-1}(n-1) - k(n)\bar{r}^H(n)R^{-1}(n-1)]/\lambda$
(7)	$w_{k,1}(n)=w_{k,1}(n-1)+k(n)e_{k,1}^*(n)$
(8)	end
(9)	Derive $w_{k,2},\cdots,w_{k,L}$ using the relation between Eq. (11) and (12)

To investigate the effectiveness of this scheme, we define the system capacity (symbols/second), as the total number of pure data symbols per frame time. The capacities of systems using the straightforward training sequence structure and the proposed one are respectively given by

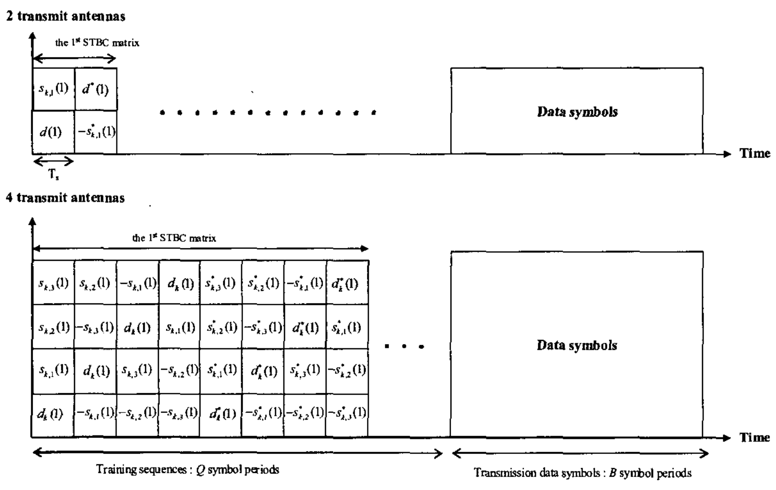

Fig. 2. Training Sequence Structure for the k-th user

$$C_S = \frac{B \cdot R \cdot M}{(B+Q) \cdot T_s} \text{ and}$$
$$C_P = \frac{(B+Q \cdot (L-1)/L) \cdot R \cdot M}{(B+Q) \cdot T_s}, \tag{12}$$

where T_s is one symbol time, B denotes the transmission periods of the data symbols, and Q denotes the training periods. The ratio of these capacities represents the capacity enhancement and is given by

$$\eta = \frac{C_P}{C_S} = 1 + \left(\frac{L-1}{L}\right) \cdot \frac{Q}{B}. \tag{13}$$

Figure 3 shows a plot of η in equation (11) as a function of Q/B, which is the proportion of the training periods with respect to the data transmission periods. At $Q/B = 30\%$, the increases of system capacity for $L=2$ and 4 are 15% and 22.5%, respectively. Since Q should be greater than $2P^2M$ in order for the RLS algorithm to converge [10], for a fixed value of B, the more co-channel users there are, the more gain can be obtained.

The estimation errors for $d_k(n)$ and $s_{k,l}(n)$ in the n-th iteration of the training are given by

$$|e_{k,1}(n)|^2 = |d_k(n) - w^H_{k,1}(n-1)\bar{r}(n)|^2, \quad \text{for } d_k(n) \tag{14}$$

$$|e_{k,l}(n)|^2 = |s_{k,l}(n) - w^H_{k,l}(n-1)\bar{r}(n)|^2, \quad \text{for } s_{k,l}(n) \text{ and } 2 \le l \le L \tag{15}$$

where $w_{k,1}(n-1)$ is calculated and updated according to Tab. 1, and $w_{k,1}(n-1)$ is derived directly from $w_{k,1}(n-1)$ using the Property 1.

V. Simulation Results

Simulations were done to verify the performance of the proposed training sequence structure. The channel is assumed to be quasi-static flat fading, where the channel remains constant over one frame but changes from one frame to another in an independent manner. We consider the two synchronous co-channel users of which the first user is the desired one. The signal-to-interference ratio (SIR) at the receive antenna is assumed to be 0 dB, which means that signals from both users arrive with the same power level at the receiver, $E_1 = E_2$. The initialization constant δ, and forgetting factor λ, are taken to be 100 and 0.99, respectively.

To investigate the convergence behavior of the proposed training sequences, the ensemble averaged learning curves are plotted in Fig. 4-6. Signal-to-noise ratio (SNR=E_1/σ_n^2) is set to 20 dB. The MSE is averaged over 200 independent realizations. We can identify that the MSE for the unknown data symbols, $E\{|e_{1,l}(n)^2|\}$ where $E\{\cdot\}$ denote ensemble average and $2 \le l \le L$, shows the same convergence behavior as the one for the training symbols, $E\{|e_{1,1}(n)^2|\}$. Because the con

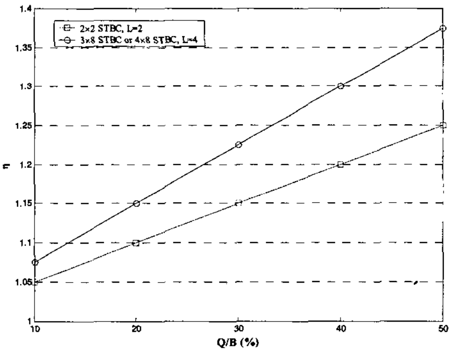

Fig. 3. Q/B vs. η

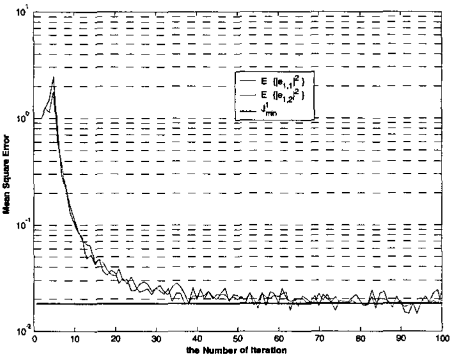

Fig. 4. Ensemble averaged learning curve two co-channel users using 2×2 STBC (SIR = 0 dB)

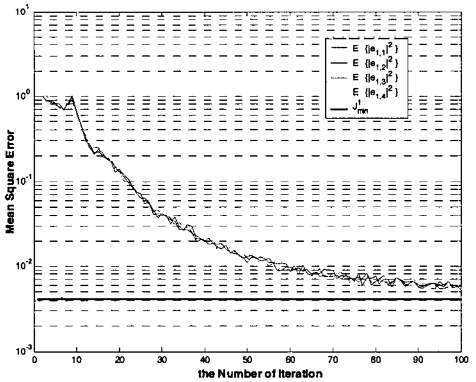

Fig. 5. Ensemble averaged learning curve two co-channel users using 3×8 STBC, SIR = 0 dB

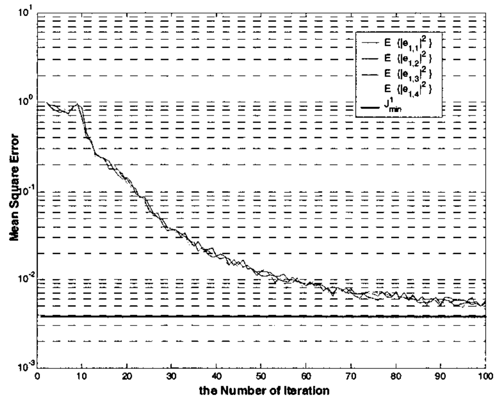

Fig. 6. Ensemble averaged learning curve two co-channel users using 4×8 STBC (SIR = 0 dB)

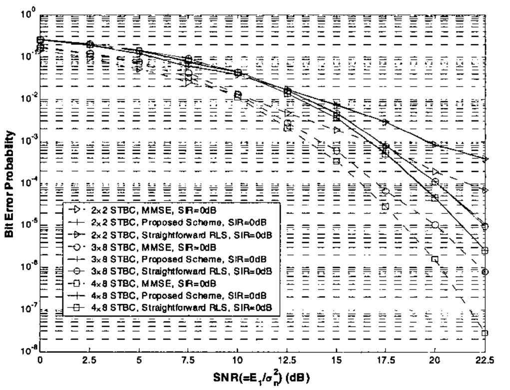

Fig. 7. BER performance (M=2, N=2, 3, 4, and SIR=0 dB)

vergence behavior of $E\{|e_{1,1}(n)^2|\}$ can be seen as the one of the straightforward RLS of [5], we can infer that the system using the proposed training sequence shows the same bit error rate (BER) performance with the straightforward RLS. For the comparison, the MSE of MMSE detector is also included.

Figure 7 shows the BER performance of the proposed scheme, straightforward RLS and the MMSE detector for the transmission of 2 bits/s/Hz using two, three and four transmit antennas with two synchronous users. Simulations were done for 10,000 frames. A frame size of $200 \times P$ bits was used. The training sequences consist of $2P^2M$ symbol times ($2PM$ STBC matrices). From the known training symbols, one weight vector is estimated using the RLS algorithm and the other weight vectors are directly derived using the relation between equations (8) and (9). The data symbols are separately decoded in a simple symbol by symbol way, without using the maximum likelihood decoding method described in [2] and [5]. For two transmit antennas, we employ the QPSK constellation. In the case of three and four transmit antennas, the 16-QAM constellation is used. The proposed scheme shows the same performance as RLS for two, three and four transmit antennas. The performance of the MMSE detector provides the lower bound of the various adaptive detectors based on MSE, where the channel information and interferences are assumed to be perfectly estimated at the receiver. Owing to the errors in the weight vector coefficients, the RLS scheme shows worse performance than the MMSE detector.

Ⅵ. Conclusion

In this paper, we proposed an efficient training sequence structure for adaptive linear multiuser detectors in space time block coded multiuser systems. The simulation results show that the proposed scheme yields the same performance as RLS, while wasting less system capacity in training mode. The proposed scheme can be used not only with the RLS algorithm, but also with the adaptive algorithms based on the mean square error criterion, so as to lower their system overhead requirements and reduce their complexity[7].

REFERENCE

〔1〕 A. F. Naguib, N. Seshadri, and R. Calderbank, "Increasing data rate over wireless channels," *IEEE Signal Processing Mag.*, vol. 17, pp. 76-92, May 2000.

〔2〕 A. F. Naguib, N. Seshadri, and A. R. Calderbank, "Applications of space-time block codes and interference suppression for high capacity and high data rate wireless systems," *Proc. 32nd Asilomar Conf. Signals, Systems, and Computers*, vol. 2, pp. 1803~1810, Nov. 1998.

〔3〕 S. M. Alamouti, "A simple transmit diversity techniques for wireless communications," *IEEE J. Select. Areas Com.*, vol. 16, pp. 1451 - 1458, Oct. 1998.

〔4〕 A. Stamoulis, N. Al-Dhahir, and A. R. Calderbank, "Further results on interference cancellation and space-time block codes," *Proc. 35th Asilomar Conf. Signals, Systems, Computers*, Pacific Grove, CA, pp. 257~261, Nov. 2001.

〔5〕 V. Mahinthan, B. Kannan, and A. Nallanathan, "Performance of LSE-RLS-based interference cancellation scheme for STBC multiuser systems," *Electronics Letters*, vol. 38, no. 25, pp. 1729~1730, Dec. 2002.

〔6〕 S. Verdu, *Multiuser Detection*, U.K.: Cambridge University Press, 1998.

〔7〕 H. C. Hwang, S. H. Shin, C. J. Lee, and K. S. Kwak, "Receivers for Spatially Multiplexed Sapce-Time Block Coded Systems: Reduced Complexity," *KICS Journal*, vol. 29, no. 11A, pp. 1244~1252, November 2004.

〔8〕 V. Tarokh, Hamid Jafarkhani, and A. R. Calderbank, "Space-time block coding for wireless Communications : Performance Results," *IEEE J. Select. Areas Com*, vol. 17, no. 3, pp. 451~460, March 1999.

〔9〕 A. Paulraj, R. Nabar, and D. Gore, *Introduction to Space-Time Wireless Communications*, 1st Ed., Cambridge University Press, 2003.

〔10〕 S. Haykin, *Adaptive Filter Theory*, 3rd Ed. Englewood Cliffs, NJ : Prentice Hall, 1996.

〔11〕 G. Woodward and B. S. Vucetic, "Adaptive Detection for DS-CDMA," *Proceedings of the IEEE*, vol. 86, no. 7, pp. 1413~1434, July 1998.

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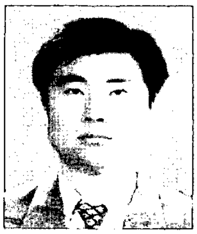
Hyun Taek Seok ***Regular Member***



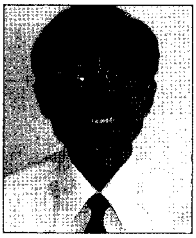
February 1984, B.S. in Electronics from JungAng Univ.
February 1986, M.S in Electronics from JungAng Univ.
February 2003, Ph.D. in Electronics from Inha Univ.
March 1996~Present, Ph.D. Candidate in Electronics from Inha Univ.
March 1986~February 1994, Researcher at Korea Telecommunication

March 1994~February 1999, Professor at Dept. of Electronics of Kyungbook College

March 1999~Present, Professor at Dept. of Commun. Eng. of KyungMin College

<Research Interests> Artificial Intelligence, Radar

Hyung Ki Lee *Regular Member*



February 1985, B.S. in Electronics from Inha Univ.

August 1987, M.S in Electronics from Inha Univ.

June 1989~March 1992, Researcher at LG Telecom. Network Center

February 1998~Present, Ph.D. Candidate in Electronics from Inha Univ.

March 1992~Present, Associate Professor at Dept. of Commun. Eng. of Jai-Neung College

<Research Interests> MIMO, WLAN, UWB

Dong Kwan Yoo *Regular Member*

February 1987, B.S. in Electronics from Inha Univ.

February 1989, M.S in Electronics from Inha Univ.

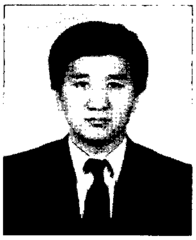
January 1989~February 1998, Senior Researcher at LG Telecom.

February 2001~Present, Ph.D. Candidate in Electronics from Inha Univ.

March 1998~Present, Professor at Dept. of Commun. Eng. of Dong-Seoul College

<Research Interests> MIMO, WLAN, UWB

Kyung Sup Kwak *Regular Member*



February 1977, B.S. in Electrical Engineering from Inha University

February 1979, M.S. in Electrical Engineering from Inha University

December 1981, M.S. in Electronics from USC

February 1988, Ph.D. in Communication Engineering from UCSD

February 1988~February 1989, Researcher at US Hughes Network Systems

February 1989~March 1990, Researcher at US IBM Network Analysis Center

January 1995~November 1999, Director for IEEE Seoul Section

March 2000~February 2002, Dean of the School of Information & Telecommunications at Inha University

January 2002~Present, vice-president at Korean Institute of Communication Science

<Research Interests> Satellite Communication, Multimedia Communication, UWB, wireless communication