Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 15 (3): 602-605, 2015
ISSN 1812-5654

ansinet
Asian Network for Scientific Information

RESEARCH ARTICLE OPEN ACCESS

DOI: 10.3923/jas.2015.602.605

Correntropy-Based Blind Channel Estimation for MIMO-OFDM Systems

Khaled Abdulaziz Alaghbari, Lim Heng Siong and W.C. Alan Tan
Communication Systems and Algorithms Research Laboratory, Faculty of Engineering and Technology, Multimedia University, Jalan Ayer Keroh Lama, Melaka, 75450, Malaysia

ARTICLE INFO
Article History:
Received: October 30, 2014
Accepted: December 06, 2014

Corresponding Author:
Khaled Abdulaziz Alaghbari,
Communication Systems and Algorithms Research Laboratory,
Faculty of Engineering and Technology,
Multimedia University,
Jalan Ayer Keroh Lama,
Melaka, 75450, Malaysia

ABSTRACT
In this study, a new correntropy Independent Component Analysis (ICA) based blind channel estimator for Multiple-input Multiple-output Orthogonal Frequency-Division Multiplexing (MIMO-OFDM) is proposed. Simulation results show that performance of the proposed method is better than that of Second-Order Blind Identification (SOBI) based method for temporally correlated sources.

Key words: Correntropy, blind channel estimation, MIMO-OFDM

INTRODUCTION

The next generation wireless communication systems are required to provide very high data-rate and guaranteed Quality of Service (QoS) over hostile radio channels. To this end, accurate Channel State Information (CSI) is required at the receiver. Most of the channel estimation methods use training sequences (or pilots) to estimate the channel gains. However, channel capacity is wasted due to the transmission of pilot symbols. To avoid this problem, efficient blind channel estimation algorithms can be used.

Blind channel estimation for MIMO-OFDM systems based on Blind Source Separation (BSS) is currently an active area of research. Gao *et al.* (2003) presented a blind channel estimator for MIMO-OFDM systems using SOBI algorithm. The SOBI algorithm relies only on the second-order statistics (e.g., correlation) of the received signal (Belouchrani *et al.*, 1997). It is well known that second-order statistics is not sufficient for BSS. Recently, a BSS algorithm based on correntropy ICA was formulated by Li *et al.* (2007) for separating both i.i.d., sources and temporally correlated sources with distinct spectra. Correntropy is a generalized correlation function between two random processes (Santamaria *et al.*, 2006). Unlike the conventional correlation function, the correntropy function contains both the higher-order statistics and temporal structure of the random processes. Motivated by the property of the correntropy, we propose a blind channel estimator based on correntropy ICA for MIMO-OFDM and show that its performance is better than that of SOBI based method proposed by Gao *et al.* (2003). To the best of our knowledge, this is the first work which applies correntropy ICA in blind MIMO-OFDM channel estimation.

METHODOLOGY

System model: We consider a typical MIMO-OFDM system model, with M_t transmit antennas, M_r receive antennas and N subcarriers (Gao *et al.*, 2003). We assume that the length of the cyclic prefix is greater than the length of channel impulse response to avoid intersymbol interference (ISI) and to maintain subcarrier orthogonality. Hence, the frequency selective-fading channel is converted into parallel flat-fading channels. After removing the cyclic prefix and performing Discrete Fourier Transform (DFT), the kth subcarrier of the received signal can be written as:

$$x(k) = H(k)s(k)+n(k),\ k = 1, 2\ldots, N \tag{1}$$

where, s(k) is a vector of M_t unknown independent source signals and n(k) is the additive Gaussian noise corrupting the signal. The $M_r \times M_t$ unknown channel coefficient matrix is defined as:

$$H(k) = \begin{bmatrix} H_{11}(k) & \cdots & H_{1M_t}(k) \\ \vdots & \ddots & \vdots \\ H_{M_r}(k) & \cdots & H_{M_r M_t}(k) \end{bmatrix}$$

Where:

$$H_{ij}(k) = \sum_{n=0}^{N-1} h_{ij}(n).e^{-j\left(\frac{2\pi}{N}\right)nk}$$

is the kth subcarrier of the frequency response of the channel between transmit antenna j and receive antenna i. The problem is to estimate H(k) by exploiting the statistical independence between the source signals and the different spectral contents of the signals.

BSS-based blind channel estimation: The blind channel estimation problem in Eq. 1 corresponds to a BSS problem of linear instantaneous mixtures with mixing matrix H(k), sources s(k) and mixtures x(k).

Second-Order Blind Identification (SOBI): SOBI based blind channel estimator for MIMO-OFDM system is proposed by Gao *et al*. (2003). It depends only on second-order statistics that are based on a joint diagonalization of several covariance matrices (Belouchrani *et al*., 1997). However, SOBI is unable to quantify statistical properties beyond the second order moments (Li *et al*., 2007).

SOBI algorithm can be summarised as follows:

Step 1: Estimate the sample covariance (or mean removed correlation) matrix R_x of x(k):

$$R_x = \frac{1}{N}\sum_{k=1}^{N} x(k)x^T(k)$$

Step 2: Compute the whitening matrix Q using Eigenvalue Decomposition (EVD) or Singular Value Decomposition (SVD) of $R_x = U_X D_X U^T_X$. Then, determine the whitened signal $\bar{x}(k) = D_x^{-1/2} U_x^T x(k) = Qx(k)$

Step 3: Estimate a set of covariance matrices $\hat{R}_{\bar{x}}(m)$ of the whitened signal $\bar{x}(k)$ for fixed lag m $\hat{R}_{\bar{x}}(m) = E[\bar{x}(k)\bar{x}^T(k-m)]$

Step 4: Simultaneously apply Jacobi techniques on the above covariance matrices set to estimate an orthogonal matrix $U_{\bar{x}}$ which diagonalizes the covariance matrices

Step 5: Finally, the estimated mixing matrix can be obtained as:

$$\hat{H} = Q^{-1}U_{\bar{x}}$$

Correntropy ICA: Correntropy is a measure of similarity and it is analogous to the correlation of two random processes. It can be shown that the series expansion for correntropy contains higher-order moments of the data (Li *et al*., 2007). In correntropy ICA the BSS problem in Eq. 1 can be solved by finding an $M_t \times M_r$ demixing matrix W such that the output $y(k) = W\bar{x}(k)$ is the best approximation to the source signals s(k), where $\bar{x}(k)$ is the whitened version of x(k).

The cross-correntropy function of two discrete strictly stationary stochastic processes $y_1[k]$ and $y_2[k]$ is given by (Li *et al*., 2007):

$$V[l] = E[K(y_1[k]-y_2[k-l])] \quad (2)$$

where, K(•) is a kernel function and E(•) is the expectation operator.

The cross-correntropy function can be estimated with the sample mean, i.e.:

$$\hat{V}[l] = \frac{1}{N-l}\sum_{k=l+1}^{N} K(y_1[k]-y_2[k-l]), \text{ for } l \geq 0 \quad (3)$$

In this study, we consider the Gaussian kernel function:

$$K(x) = \frac{1}{\sqrt{2\pi}\sigma_{ker}}\exp-\left(\frac{\|x\|^2}{2\sigma^2_{ker}}\right) \quad (4)$$

where, σ_{ker} is the kernel size.

A necessary condition for two strictly stationary stochastic processes to be independent is V[0] = V[l] for all l (Li *et al*., 2007). The demixing matrix W can then be found by minimizing the cost function (Li *et al*., 2007):

$$J = \sum_{l=-L}^{L} (V[0]-V[l])^2 \quad (5)$$

Using the gradient descent approach for minimizing J the update equation for the demixing matrix W is:

$$W_{t+1} = W_t - \eta(\nabla_w J) = W_t - \eta\sum_{l=-L}^{L}\left(\hat{V}[0]-\hat{V}[l]\right)\left(\nabla_w\hat{V}[0]-\nabla_w\hat{V}[l]\right) \quad (6)$$

where, η is a step size and:

$$\nabla_w\hat{V}[l] = \frac{1}{N-l}\sum_{k=l+1}^{N} K(y_1[k]-y_2[k-l])(y_1[k]-y_2[k-l])\begin{bmatrix} -x_1[k] & -x_2[k] \\ x_1[k-l] & x_2[k-l] \end{bmatrix} \quad (7)$$

for l = 0, ±1,...±L.

The blind channel estimator based on correntropy ICA is summarized as follow:

Step 1: Compute eigenvalue decomposition (EVD) of:

$$R_x = \frac{1}{N}\sum_{k=1}^{N} x(k)x^T(k)$$

$$R_x = U_x D_x U_x^T$$

where, R_x is the $M_t \times M_r$ correlation matrix, D_x is a diagonal matrix containing the eigenvalues of matrix R_x and the column vectors of U_x are the corresponding eigenvectors.

Step 2: Perform pre-whitening of the received signal $\bar{x}(k) = D_x^{-1/2} U_x^T x(k) = Qx(k)$

Step 3: Initialize a $M_t \times M_r$ demixing matrix W = I

Step 4: Compute $y(k) = W\bar{x}(k)$

Step 5: Compute the correntropy $\hat{V}[l]$ and its corresponding gradient $\nabla_w \hat{V}[l]$ for $l = 0, \pm 1, \ldots, \pm L$ using Eq. 3 and 7, respectively

Step 6: Update the demixing matrix W using Eq. 6

Step 7: Repeat steps (4-6) until a stopping criterion is satisfied

Step 8: The channel gain can then be estimated as $\hat{H} = W^{-1}Q^{-1}$

RESULTS AND DISCUSSION

An MIMO-OFDM system with 2 transmitters, 2 receivers and N = 256 subcarriers is considered. OFDM signals based on BPSK modulation are employed. Two different pre-filters with transfer functions $P_1(z) = 1/(1+0.5z^{-1})$ and $P_2(z) = 1/(1+0.3z^{-1})$ (Gao *et al*., 2003) are applied to the two source signals. The wireless channel is assumed to be slowly-varying frequency selective-fading channel. Therefore, the blind estimators can be applied to each subcarrier to obtain estimate for H(k) using x(k) (Gao *et al*., 2003). The performance of the blind channel estimators is measured by the Mean Square Error (MSE) and the Signal-to-Distortion Ratio (SDR) with the assumption that there is no scaling and phase ambiguity (Amari *et al*., 1996). The MSE and SDR are defined in Eq. 8 and 9, respectively:

$$\text{MSE} = 10\log_{10}\frac{1}{N}\left(\left|\hat{H}(k)\right| - \left|H(k)\right|\right)^2 \quad (8)$$

$$\text{SDR} = -10\log_{10}\frac{1}{N}\sum_{k=1}^{N}\left[\frac{1}{M_t(M_r-1)}\sum_{i=1}^{M_r}\left(\frac{\sum_{j=1}^{M_r}|P_{ij}|}{\max_j|P_{ij}|}-1\right)\right] \quad (9)$$

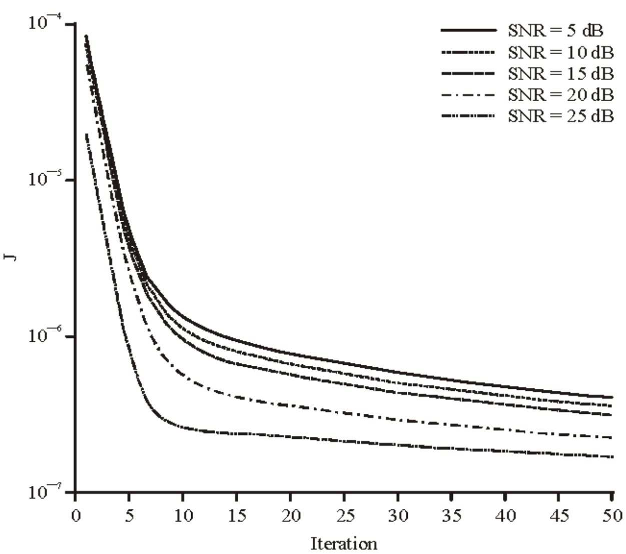

Fig. 1: Cost function of correntropy ICA versus iteration at different SNRs

where, $P = \hat{H}(k)^{-1}H(k)$. The results shown in the below plots are obtained from Monte-Carlo simulations, averaged of 100 independent runs.

In Fig. 1, the learning curve for correntropy ICA based blind estimator is shown for different SNRs. The graph shows that, 10 iterations will be sufficient for the algorithm to converge. In Fig. 2, we compare the MSE performance of the blind channel estimators based on SOBI and correntropy ICA in additive white Gaussian noise. The graph shows that the correntropy ICA based method outperforms the SOBI based method. For low SNR there is improvement of about 1.5 dB and for high SNR an improvement of more than 3 dB can be achieved by correntropy ICA based method. Figure 3 shows the result obtained when more OFDM symbols are utilized in the estimation. The performance in terms of SDR improves with increased number of OFDM symbols. Improvement of

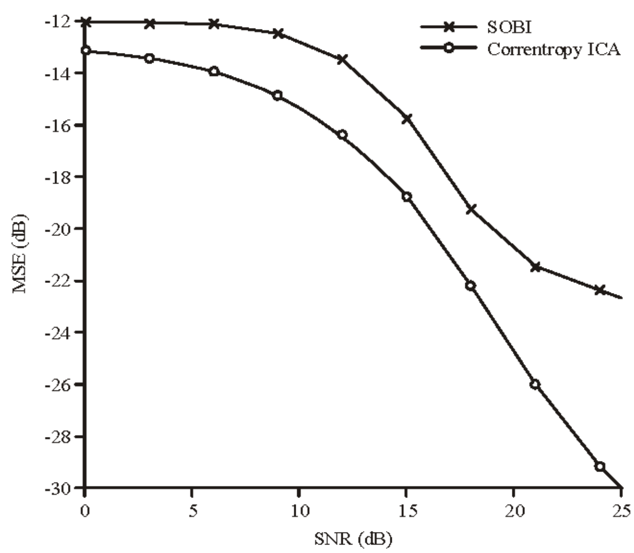

Fig. 2: MSE performance of blind channel estimators in MIMO-OFDM system

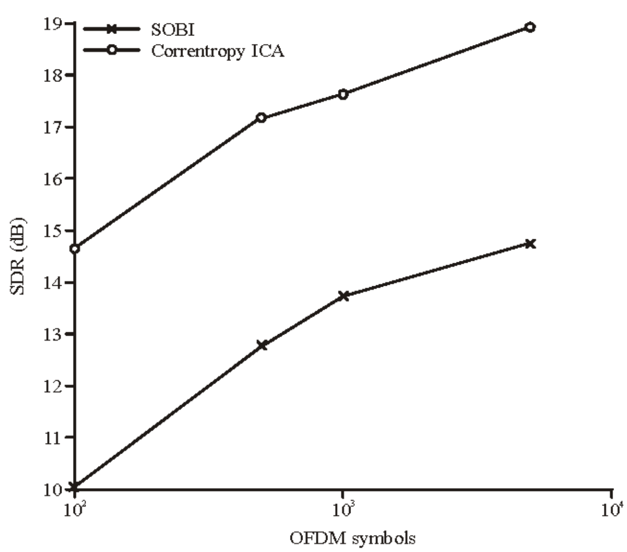

Fig. 3: SDR versus MIMO-OFDM symbols at SNR = 15 dB

more than 4 dB can be achieved by correntropy ICA compared to SOBI based method in terms of SDR. The results in Fig. 2 and 3 show the effectiveness of the proposed method when the signal sources are temporally correlated processes with non-overlapping spectra. This is because correntropy is able to extract not only the second-order statistics but also the higher order information of the sources.

CONCLUSION

In this study, we have proposed a new correntropy ICA based blind channel estimator for MIMO-OFDM systems. Simulation results show that performance of correntropy ICA based estimator in temporally correlated sources is better than that of the SOBI based method.

ACKNOWLEDGMENTS

This study was sponsored in part by the Ministry of Higher Education under the FRGS Grants FRGS/2/2010/TK/MMU/02/2 and FRGS/1/2012/TK06/MMU/02/5.

REFERENCES

Amari, S., A. Cichocki and H.H. Yang, 1996. A New Learning Algorithm for Blind Signal Separation. In: Advances in Neural Information Processing Systems 8, Touretzky, D.S., M.C. Mozer and M.E. Hasselmo (Eds.). MIT Press, Cambridge, MA., USA., ISBN-13: 9780262201070, pp: 757-763.

Belouchrani, A., K. Abed-Meraim, J.F. Cardoso and E. Moulines, 1997. A blind source separation technique using second-order statistics. IEEE Trans. Signal Process., 45: 434-444.

Gao, C., M. Zhao, S. Zhou and Y. Yao, 2003. Blind channel estimation algorithm for MIMO-OFDM systems. Electron. Lett., 39: 1420-1422.

Li, R., W. Liu and J.C. Principe, 2007. A unifying criterion for instantaneous blind source separation based on correntropy. Signal Process., 87: 1872-1881.

Santamaria, I., P.P. Pokharel and J.C. Principe, 2006. Generalized correlation function: Definition, properties and application to blind equalization. IEEE Trans. Signal Process., 54: 2187-2197.