Interference Cancellation in MIMO Systems

Zoltán Németh, Sándor Imre

Budapest University of Technology and Economics, Department of Telecommunications,
Mobile Communications and Computing Laboratory
H-1117 Budapest, Magyar Tudósok krt. 2., Hungary
Tel.: 36-1-463-3227
email: pepa@mcl.hu

***Abstract*-- The MIMO systems have many advantages compared to single transmissions. However, the interference load is increased, causing difficulties in transmission. A possible solution for the problem is provided by the BSS, which is an application of ICA. The two main classes of ICA algorithms (the batch and adaptive algorithms) have different advantages and drawbacks that should be considered while solving a problem.**

***Index terms*-- MIMO systems, interference cancellation, blind source separation, independent component analysis**

I. INTRODUCTION

In mobile and fixed wireless networks there is high demand on data rates. Therefore in case of broadband wireless communication networks improvement of the spectral efficiency (the bitrate per unit bandwidth, b/s/Hz) is required. Among the transmission techniques based on this principle one can mention the various adaptive antenna arrays, the multiple input multiple output (MIMO) systems, the adaptive coding and modulation techniques, and the level-dependent procedures [6].

In wireless networks of the future the transmission systems that bear the ability of continuous adaptation to radio channel can be very promising in point of view of spectral efficiency and improvement of transmission rate. However, due to the several parallel communications the interference load is high in these systems, which induces a difficult problem to solve. In this article we examine the adaptive MIMO systems and especially a promising interference cancelling method in this environment.

II. MIMO SYSTEMS

An adequate equipment in wireless communications, that the multiple input multiple output systems can be realized by, are the smart antenna systems. The most important property of these architectures is the adaptivity, which allows the optimal or near optimal feeding of each antenna element as a function of the state of the continuously varying transmission channel. The model of the system can be written as in Equation 1:

$$\mathbf{x} = \mathbf{A}\mathbf{s} + \mathbf{n} \qquad (1)$$

where **s** is the vector of the source signals arriving into the channel, **x** means the vector of the mixed signals, leaving the channel and arriving into the receiver antennas, **A** stands for the channel matrix and **n** is the additive noise vector [3]. In MIMO systems the incident dataflow is divided and after the transmission these signals are reunited. Techniques of dividing and reuniting the signal streams, like adaptive modulating and coding procedures, are usually called link adaptation (LA) methods.

Lately significant improvement has been performed in the field of link adaptation, and the applications of results that has been achieved, are widespread in wireless communication. The new techniques are efficient in antenna systems applying time, frequency, spatial, etc. division multiplexing methods.

III. ADAPTATION, EQUALIZATION AND SOURCE SEPARATION

Exploiting the advances provided by the multiple channels the optimal or near optimal transmission control is possible [2]. Robustness of the transmission is also required, therefore redundancy, diversity shouldbe provided. By the simplest solution ARQ methods can be applied. The redundancy can be built into the system in respect of several other parameters, thus frequency, spatial and code diversities are also available. The space-time coding methods are also created with similar purposes [3].

Measurement of the continuously varying channel parameters is required for link adaptation, channel equalization and interference suppression, respectively. These are called channel state information (e.g. SINR). The exact measurement is usually problematic, but the task can be significantly simplified if the first, second, etc. order statistics of the channel state information is examined only within a given time interval [1].

In case of channel equalization and interference cancellation the channel state information is formed by the elements of the inverse of the channel matrix, which are described with time variant functions. For the sake of complexity reduction, certainly, one can also use statistics of the signals within a time interval, which is longer than the sampling time [4]. Having the channel state information or its statistics it should be feedbacked, thus effective bandwidth is reduced due to the additional information flow. Therefore it is worth examining the blind equalization methods, which do not require any additional information feedback. We should remark that elimination of the feedback does not mean that ability of adaptation has lost!

Assuming that the source signals are independent, the signal restoring can be performed by using the methods of independent component analysis (ICA). In this case blind source separation (BSS) is executed and interfering signals are suppressed. For this task fourth order statistics should be used, because the second and third order statistics are insufficient. If examining second order statistics, only the correlation of the signals are known which is inadequate for establishing independence. Similar to the second order statistics, the third order one is also unusable for examining independence. The reason for it is that in case a stochastic process has symmetric distribution (e.g. Gaussian, Laplacian), then the third order cumulant equals zero, therefore these processes are undistinguishable in the third order statistics.

The source separation algorithms can be divided into to groups: adaptive and the so called batch algorithms exist. The batch algorithms operates in off-line mode, accordingly every samples of the signals should be "collected" before performing the transformation. Extraction of the source signals and identification of the inverse of the channel matrix are based on the statistical parameters of the received data set. The advantage of these methods is that in case of relatively small number of samples and after few iteration steps they give sufficiently good results [5]. However, drawback also should be mentioned: due to their principle of operation these methods can not be used in real-time communications.

Among the batch procedures the so called fast robust fix-point algorithm seems to be the best choice for signal separation [7]. A step of this method and renormalization are shown in Equations 2 and 3:

$$\mathbf{w}^{+}=E\{\mathbf{x}g(\mathbf{w}^{T}\mathbf{x})\}-E\{g'(\mathbf{w}^{T}\mathbf{x})\} \quad (2)$$

$$\mathbf{w}^{*}=\mathbf{w}^{+}/||\mathbf{w}^{+}|| \quad (3)$$

where $\mathbf{w}$ means the rows of the separation matrix (proportional with the inverse of the channel matrix), $(.)^T$ is the operation of transposition $E\{.\}$ means expected value, g(.) stands for a vectorial non-linearity and ||.|| means the Eucledian norm of a vector. To keep the consistence with the former notations, $\mathbf{x}$ stands for the vector of the received signals. After some iterations one of the source signals can be extracted. Then this vector should be subtracted from the vector space (and renormalization is also needed) to avoid convergence to the same vector. This operation can be performed as written in Equations 4 and 5:

$$\mathbf{w}_{p+1}=\mathbf{w}_{p+1}-\sum^{p}_{j=1} \mathbf{w}^{T}_{p+1}\mathbf{w}_j\mathbf{w}_j \quad (4)$$

$$\mathbf{w}_{p+1}=\mathbf{w}_{p+1}/\mathrm{sqrt}(\mathbf{w}^{T}_{p+1}\mathbf{w}_{p+1}) \quad (5)$$

where letter p means the number of source signals have already restored [7].

The other division of separating algorithms consists of adaptive or on-line algorithms which continuously refine the elements of the channel matrix according to the received symbols [5]. The main advantage of adaptive techniques is that their computational complexity is low compared to the batch procedures, therefore these methods can be more efficiently applied in case of high speed communications.

One of the most effective adaptive methods is the equivariant adaptive separation via independence (EASI) algorithm. The rule of every transformation step is described in Equation 6:

$$\mathbf{W}_{n+1} = \mathbf{W}_n - \left[\lambda \frac{\mathbf{x}\mathbf{x}^T - \mathbf{I}}{1 + \lambda \mathbf{x}^T \mathbf{x}} + \frac{g(\mathbf{x})\mathbf{x}^T - \mathbf{x}\, g^T(\mathbf{x})}{1 + \lambda \left| \mathbf{x}^T g(\mathbf{x}) \right|} \right] \mathbf{W}_n \quad (6)$$

where **I** stands for the identity matrix, λ is the adaptation step size, and g(.) is an adequate componentwise nonlinear odd function [8].

IV. SIMULATION RESULTS

During the test of adaptive and batch algorithms of independent component analysis we have used MATLAB simulation environment.

Firstly we have tested the most promising batch method: the fast and robust fixed-point algorithm. In the simulation we assumed N= 2, 4 and 8 independent BPSK modulated source signals, of course in 2 (4, 8)-input 2 (4, 8)-output MIMO arrangements. Number of samples or length of data packages is chosen 33000. The reason for it is a practical consideration. In a widespread standard IEEE 802.11 for wireless LANs the maximal package size is 32888, roughly 33000 bits ((4095 data bytes + 16 header bytes)∗8=32888 bits) [9]. In the simulation 5 iteration step is performed with every data stream, while tanh(.) is chosen for g(.) non-linearity. The small number of iteration steps clearly shows the efficiency of the algorithm. The average (over 2, 4 and 8 receivers) bit error ratio in the receiver side is plotted in Figure 1.

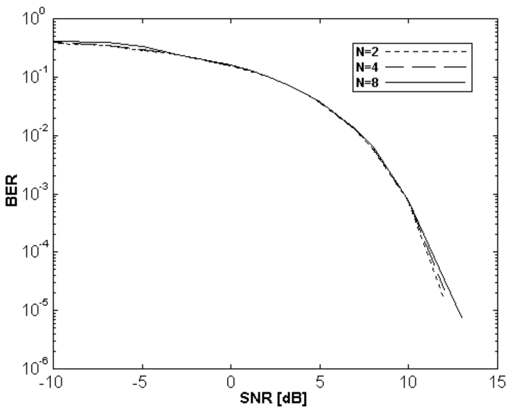

Figure 1 BER as a function of SNR in case of batch method

One can see that this method operates adequately in case of low signal-to-noise ratio. In higher SNR ranges the bit error ratio converges extremely fast to zero. The BER value of 10^{-5} is reached at roughly 12 dB. We can state that the difference in case of various number of sources and receivers (2, 4, 8) is not significant in this point of view. Effect of change in number of samples has also been tested and shown in Figure 2. We assumed noiseless case in 2-2, 4-4 and 8-8 (transmitter – receiver) MIMO environment,

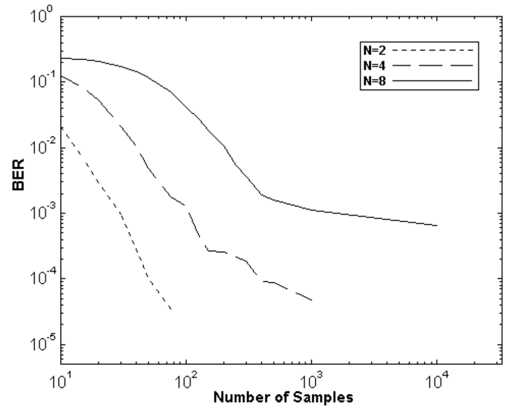

Figure 2 Sample number dependence of the BER in case of batch method

respectively. Our simulations have shown that the algorithm provides good performance except in case of very low number of symbol samples. As one can see, in case of higher number of samples the performance of the algorithm and consequently the bit error ratio highly depends on the number of transmitters and receivers. The smaller number of the interfering sources, the lower the bit error ratio.

While simulating adaptive methods, the so called EASI (equivariant adaptive separation via independence) algorithm was used, which provides good solution. In case of this simulation we also assumed 2 (4, 8)-input 2 (4, 8)-output MIMO arrangement with BPSK modulated independent source signals. Number of samples or length of data packages is also chosen 33000 bits in the first simulation. The adaptation step size, λ is set to 0.02 and tanh(.) is chosen for g(.) non-linearity. We examined the average (over 2, 4 and 8 receivers) bit error ratio as a function of signal-to-noise ratio in the receiver side. Our solution is plotted in Figure 3.

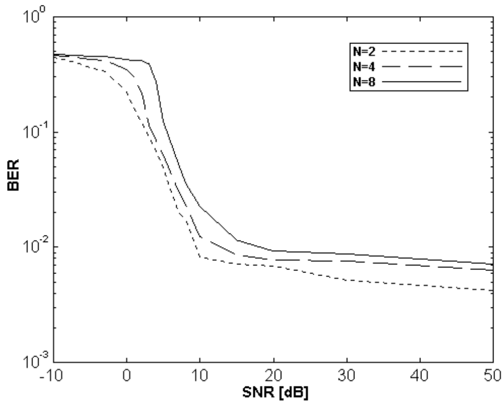

Figure 3 Effect of noise in case of adaptive method

Similarly to the batch algorithm, small differences are observable among the three curves. These deviations are higher than in the batch case, but are also not significant. However, the smaller number of communicating elements results in slightly better performance.

The performance of the adaptive algorithm also depends on the number of received samples. While testing this relation we set the same conditions as in case of the former simulation except we assumed noiseless environment. The results are shown in Figure 4. One can also see that in case of increasing number of samples, the bit error ratio decreases. This

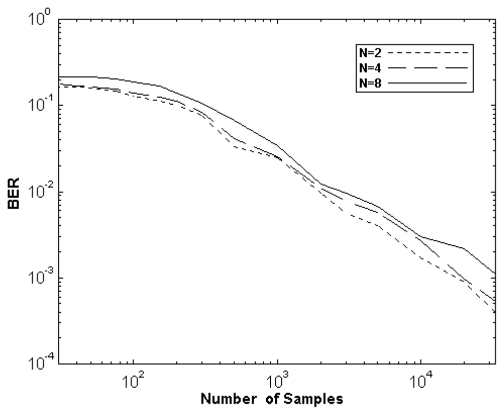

Figure 4 Sample number dependence of the BER in case of adaptive method

effect is a typical property of adaptive algorithms as well. Effect of change in number of transmitters and receivers is not relevant.

V. SUMMARY

Due to the ascendant requirements in wireless services the widespread use of MIMO systems is expectable. Due to the heavy interference load interference suppression, source separation are required. In this article we have shown solutions with ICA-BSS methods. Among the batch procedures we examined the performance of fast and robust fixed-point algorithm. This algorithm has low BER also in low SNR range, however the computational load is heavy. Conversely, adaptive methods work faster and lower bit error ratio can be reached. A promising method for adaptive source separation is proven by the EASI algorithm. We have also tested this method and shown that if the number of samples is high enough the BER becomes adequate.

VI. REFERENCES

[1] S. Catreaux, V. Erceg, D. Gesbert, R. W. Heart Jr.: „Adaptive Modulation and MIMO coding for Broadband Wireless Data Networks”, IEEE Communications Magazine, June 2002, Vol. 40, No. 6, pp108-115

[2] H. Sampath, S. Talwar, J. Tellado, V. Erceg, A. Paulraj: „A Fourth-Generation MIMO-OFDM Broadband Wireless System: Design, Performance, and Field Trial Results”, IEEE Communications Magazine, September 2002, Vol. 42, No. 9, pp143-149

[3] T.S. Rappaport: „Wireless Communications”, 1996, New Jersey, Prentice Hall, pp180-185

[4] G.B. Giannakis, Y. Hua, P. Stoica, L. Tong: Signal Processing Advances in Wireless and Mobile Communications, Trends in Channel Estimation and Equalization”, 2001, Upper Saddle River, Prentice Hall, pp65-92

[5] Z. Németh, F. Balázs, S. Imre: „Comparison of Overcomplete Independent Component Analysis Algorithms”, Signal Processing, Pattern Recognition and Applications (SPPRA 2002), 25-28 June 2002, Hersonissos, Greece, ACTA Press, pp13-18

[6] Z. Németh, F. Balázs, S. Imre: „MIMO rendszerek összeköttetés adaptációja”, Híradástechnika, Budapest, February 2003, pp10-17

[7] Aapo Hyvärinen: ”Fast and Robust Fixed-Point Algorithms for Independent Component Analysis, IEEE Transactions on Neural Networks, April 1999

[8] Y. Zhang, S. A. Kassam: ”Blind separation and equalization using fractional sampling of digital communications signal”, Signal Processing, 2001, Vol. 81, pp2591-2608

[9] ANSI/IEEE Standard 802.11, IEEE Standard for Information technology, Telecommunications and information exchange between systems, Local and metropolitan area networks, Specific requirements