RE-CONFIGURABLE SEMI-BLIND CANCELLATION OF ASYNCHRONOUS INTERFERENCE WITH AN ANTENNA ARRAY

Alexandr M. Kuzminskiy and Constantinos B. Papadias

Lucent Technologies, Bell Labs
The Quadrant, Stonehill Green, Westlea, Swindon SN5 7DJ, UK, ak9@lucent.com
791 Holmdel-Keyport Rd. Holmdel, NJ, 07733-0400, USA, papadias@lucent.com

Abstract

The antenna array asynchronous interference cancellation problem is addressed by means of semi-blind algorithms with projections to the finite alphabet. It has been observed that the conventional Least Squares (LS) solution estimated over the training interval may not be suitable for initialization of the iterative semi-blind schemes in the case of asynchronous interference. Unlike the synchronous case, a modified LS initialization based on the autocorrelation matrix estimated over the whole burst of data outperforms the conventional LS initialization for the high interference level. A re-configurable receiver is proposed in this paper, which exploits on-line selection of the initialization. Its efficiency is demonstrated in TDMA and OFDM environments.

1. INTRODUCTION

Conventional space-time equalization and interference cancellation techniques exploit the known training symbols to estimate the weight vector of an antenna array [1]. The underlying assumption for these techniques is that the training data is reliable since the co-channel interference (CCI) overlaps with the training symbols of the desired signal. Normally, this is the case for the synchronous CCI, which has the same time-frequency structure as the desired user. Asynchronous cells, packet transmission, adaptive frequency allocation or fast frequency hopping lead to more complicated asynchronous or sparse interference scenarios [2-6]. If the training data is concentrated in one part of a data slot, e.g. in midamble in a GSM/EDGE system or preamble in a HIPERLAN/2 system, then the asynchronous interference may partially overlap or not overlap with the training data of the desired signal. Training-based techniques are not effective in this case.

It is pointed out in [4] that stationary filtering can be exploited to enhance the desired signal and reject the asynchronous CCI if information data for the signal of interest is involved in the estimation of the weight coefficients together with the training data. An iterative semi-blind algorithm with projection to the finite alphabet (FA) is used in [4]. The FA property applies to the whole slot of the desired signal, thus it can be used for adjusting weights in the asynchronous CCI case. Other semi-blind algorithms can be applied in this case as well [6].

Initialization impact on the semi-blind algorithm with projection to FA is studied in [7] in both synchronous and asynchronous scenarios. It is shown in [7] that unlike the synchronous case, where the conventional training-based LS initialization demonstrates the best results, in the asynchronous case the modified initialization with autocorrelation matrix estimation over the whole data slot outperforms the conventional initialization for the low Signal to Interference Ratio (SIR). The simulation results for TDMA and OFDM systems presented in [7] show that different initializations are required in different conditions. This suggests that on-line initialization selection in a re-configurable receiver would be a promising way to improve the ability to suppress the asynchronous interference.

A re-configurable receiver is proposed in this paper. It is based on slot-by-slot selection of the initialization of the semi-blind algorithm with projection to FA. Its efficiency is illustrated by means of antenna array simulations in TDMA and OFDM (HIPERLAN/2) environments.

In Section 2 we describe the narrowband data model and formulate the problem. In Section 3 a slot-by-slot initialization selection is proposed and a re-configurable semi-blind receiver is developed. An OFDM version of the algorithm and the simulation results in a HIPERLAN/2 environment are presented in Section 4. Section 5 concludes the paper.

2. PROBLEM FORMULATION

Since our goal is to concentrate on the difference between synchronous and asynchronous CCI cancellation problems, we start from the simplified narrowband data model of the signal received by an antenna array of K elements:

$$\mathbf{x}(n) = \mathbf{h}s(n) + \sum_{m=1}^{M} \mathbf{g}_m u_m(n) + \mathbf{z}(n), \qquad (1)$$

where n is the time index (symbol sampling is assumed); $\mathbf{x}(n)$ is the $K \times 1$ vector representing the output of an antenna array; $s(n)$ is the desired signal belonging to the known FA, $u_m(n)$, $m = 1 \ldots M$ are the M components of the interference, $\mathbf{h}$ and $\mathbf{g}_m$, are $K \times 1$ vectors modeling the linear propagation channels and $\mathbf{z}(n)$ is the $K \times 1$ vector of noise. All propagation channels are assumed to be stationary over the whole burst of data and independent for different antenna elements and bursts. The desired signal and all interference components are assumed to be independent as well.

The data model is illustrated in Figure 1. The desired signal and all interference components have the same burst structure of N symbols. Independent random delays d_m, $m = 1 \ldots M$ in the interval $\pm N$ are used to model the asynchronous interference (the case of $d_m = 0$, $m = 1 \ldots M$ corresponds to the synchronous interference scenario). Independent sets of delays are used for different bursts of data to model asynchronous packet transmission.

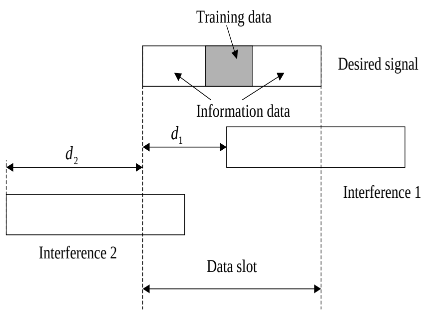

Fig. 1. Data model for two-component asynchronous CCI

A linear spatial filter for recovering the transmitted signal $\mathbf{s} = \{s(1) \ldots s(N)\}^T$ can be expressed as

$$\hat{\mathbf{s}} = \mathbf{X}\mathbf{w}, \tag{2}$$

where $\mathbf{X} = \{\mathbf{x}^T(1) \ldots \mathbf{x}^T(N)\}^T$ is the $N \times K$ data matrix and $\mathbf{w}$ is the $K \times 1$ vector of adjustable coefficients. The hard decision can be obtained by projection to the alphabet

$$\tilde{\mathbf{s}} = \Theta\{\hat{\mathbf{s}}\}. \tag{3}$$

Assuming that the N_t symbols of the desired signal at the known positions inside the processing interval are known, the problem is to determine the weight vector $\mathbf{w}$ in (2) according to some estimation criterion.

The presented simplified data model reflects the main difficulty with the asynchronous interference scenario: some of the interference components may partially overlap or not overlap at all with the training interval of the desired signal. This is not the case for the synchronous interference with $d_m = 0, m = 1 \ldots M$.

The OFDM version of the presented narrowband data model is addressed in Sections 4.

3. RE-CONFIGURABLE RECEIVER

3.1. Basic algorithm

The conventional iterative estimation algorithm with projections to the FA [4 and others] can be described as follows:

$$\hat{\mathbf{w}}^j = (\mathbf{X}^*\mathbf{X})^{-1}\mathbf{X}^*\Theta\{\mathbf{X}\hat{\mathbf{w}}^{j-1}\},\ j = 1 \ldots J, \tag{4}$$

where j is the number of the current iteration and J is the total number of iterations.

The selection of the initialization $\hat{\mathbf{w}}^0$ has critical impact on the performance of algorithm (4), e.g. arbitrary $\hat{\mathbf{w}}^0$ corresponds to blind estimation [1 and others] whereas training-based initializations correspond to semi-blind versions of the algorithm.

We consider two possible training-based initializations for iterative algorithm (4):

- the conventional LS estimator

$$\hat{\mathbf{w}}_\text{LS} = (\mathbf{X}_\text{t}^*\mathbf{X}_\text{t})^{-1}\mathbf{X}_\text{t}{}^*\mathbf{s}_\text{t}, \tag{5}$$

where $\mathbf{s}_\text{t}$ is the $N_\text{t} \times 1$ vector of the training symbols and $\mathbf{X}_\text{t}$ is the $N_\text{t} \times K$ data matrix of the received signals from the training interval,

- the modified burst-based LS estimator (LSB) [3,5 and others], which can be expressed as

$$\hat{\mathbf{w}}_\text{LSB} = (N/N_\text{t})(\mathbf{X}^*\mathbf{X})^{-1}\mathbf{X}_\text{t}{}^*\mathbf{s}_\text{t}. \tag{6}$$

It differs from (5) by the "improved" estimation of the autocorrelation matrix over the whole burst of data instead of estimation over the training interval in (5).

Selection $\hat{\mathbf{w}}^0 = \hat{\mathbf{w}}_\text{LS}$ and $\hat{\mathbf{w}}^0 = \hat{\mathbf{w}}_\text{LSB}$ leads to the LS and LSB algorithms with projections: LSP and LSBP accordingly.

It is shown in [7] that LS and LSB behave differently in the synchronous and asynchronous scenarios. Unlike the synchronous case, where LS clearly outperforms LSB, in the asynchronous case LSB outperforms LS for the low SIR. Using LS and LSB as initializations for the iterative semi-blind algorithm (4) leads to similar behaviour for LSP and LSBP. Typical simulation results shown in Figure 2 illustrate this situation. Raw Bit Error Rate (BER) averaged over 10^5 bursts is plotted in Figure 2 for fixed Signal-to-Noise Ratio SNR = 15 dB and $N_t = 8$ and variable SIR in the synchronous ($d_m = 0, m = 1 \ldots M$) and asynchronous scenarios from Section 2. Other parameters are: QPSK signaling, $K = 4$, $M = 2$, $N = 60$ and $J = 5$ (indicated in brackets, e.g. LSP(J)).

One can see in Figure 2 that contradictory to the synchronous case, a "crossing point" exists in the asynchronous case. This situation clearly demands a new solution to address the asynchronous interference cancellation problem.

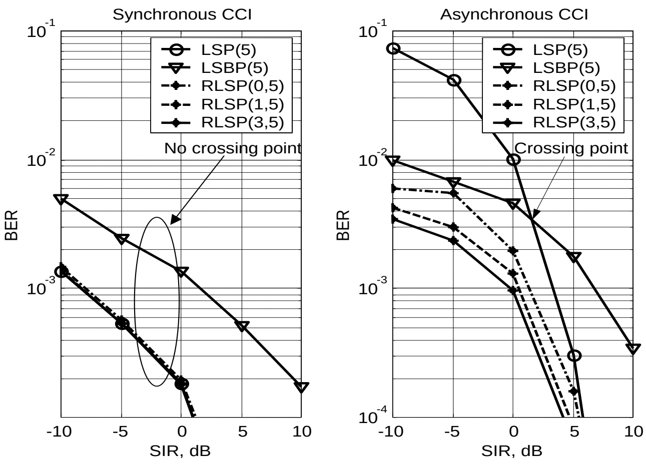

Fig. 2. BER in the synchronous and asynchronous scenarios

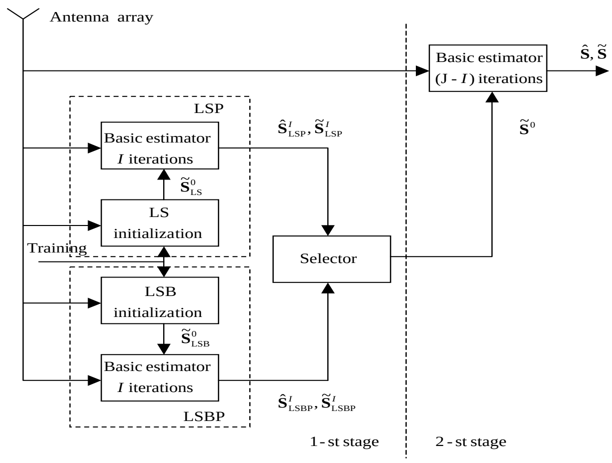

Fig. 3. Structure of the re-configurable receiver

3.2. On-line initialization selection

The key observation leading to a slot-by-slot re-configurability approach is that in the asynchronous scenario presented in Section 2, any combination of the desired signal and interference positions can be met on random basis. Some data slots with complete or almost complete overlapping between the training data and the CCI can be effectively addressed by means of the LSP algorithm, which significantly outperforms the LSBP estimator in this case. Other data slots with poor overlapping or without any overlapping can be effectively processed by means of LSBP rather than LSP. This suggests that slot-by-slot selection of the estimation algorithm may give us better results than each of the estimators applied to all slots of data separately.

A structure of a re-configurable LSP (RLSP) receiver implementing this idea is shown in Figure 3. At the first stage of processing LSP and LSBP perform I iterations in parallel. Then the Selector block selects (combines) signal estimations according to some selection criterion. At the second stage, the selected (combined) estimation of the whole slot of data is used as initialization for the basic iterative estimator (4), which performs the rest of the $(J - I)$ iterations.

To define the algorithm we need to specify a selection rule.We propose to use the distance from the FA as a metric for selection. Then the algorithm of the Selector block in Figure 3 can be expressed as follows:

$$\tilde{s}^0(n) = \begin{cases} \tilde{s}^I_{\mathrm{LSP}}(n) & \text{if} \quad r_{\mathrm{LSP}}(n) \leq r_{\mathrm{LSBP}}(n) \\ \tilde{s}^I_{\mathrm{LSBP}}(n) & \text{if} \quad r_{\mathrm{LSP}}(n) > r_{\mathrm{LSBP}}(n) \end{cases}, \quad (7)$$

where $r_{\mathrm{LSP}}(n) = |\tilde{s}^I_{\mathrm{LSP}}(n) - \hat{s}^I_{\mathrm{LSP}}(n)|^2$ and $r_{\mathrm{LSBP}}(n) = |\tilde{s}^I_{\mathrm{LSBP}}(n) - \hat{s}^I_{\mathrm{LSBP}}(n)|^2$ are the distances from the FA and $\tilde{s}^0(n)$, $\tilde{s}^I_{\mathrm{LSP}}(n)$, $\hat{s}^I_{\mathrm{LSP}}(n)$, $\tilde{s}^I_{\mathrm{LSBP}}(n)$ and $\hat{s}^I_{\mathrm{LSBP}}(n)$ are the elements of the corresponding vectors $\tilde{\mathbf{s}}^0$, $\tilde{\mathbf{s}}^I_{\mathrm{LSP}}$, $\hat{\mathbf{s}}^I_{\mathrm{LSP}}$, $\tilde{\mathbf{s}}^I_{\mathrm{LSBP}}$ and $\hat{\mathbf{s}}^I_{\mathrm{LSBP}}$, respectively, shown in Figure 3.

The complexity of the iterative estimators is approximately proportional to the total number of iterations of the basic algorithm with projections. The receiver in Figure 3 requires totally $I + J$ iterations. Hence, its complexity is roughly $(I + J)/J$ times higher that the complexity of LSP or LSBP performing J iterations.

The advantages of the proposed re-configurability approach are as follows:

- The overall performance can be better than the performance of the basic estimators applied separately.

- Complicated and normally not accurate scenario identification and estimation are not required.

- Additional complexity is reasonable compared to separate use of LSP or LSBP.

The simulation results for RLSMP(I, J) are presented in Figure 2 for fixed $J = 5$ and variable $I = 0, 1, 3$ ($I = 0$ means that the selection rule is applied to the initial LS and LSB without any iterations at the first stage in Figure 3). One can see that RLSP significantly outperforms the basic estimators, especially in the “crossing point” area. Comparison of the RLSP curves for different values of I shows a trade-off between performance and complexity.

4. RE-CONFIGURABLE OFDM RECEIVER

Considering the narrowband received signal $\mathbf{x}(n)$ in (1) and the weight vector $\mathbf{w}$ in (2) as the output of an antenna array and the weight vector at the l-th subcarrier of an OFDM system, we obtain the following reformulated notation: $\mathbf{X}$ is the total $NL \times KL$ matrix of the received signal, $\mathbf{X}_{\mathrm{t}}$ is the $N_{\mathrm{t}} \times KL$ matrix of the received signal corresponding to the training data, where N_{t} is the total number of the training symbols at all subcarriers and OFDM symbols, $\mathbf{w}$ is the total $NL \times 1$ weight vector and $\hat{\mathbf{s}}$ is the $NL \times 1$ estimated signal vector, where L is the number of subcarriers.

Different approaches can be applied for formulation of the OFDM versions of the LSP and LSBP algorithms, such as group-based [8] or model-based [9] techniques. Following [9] we use the linear model for the antenna array weight coefficients to reduce the dimension of the problem:

$$\mathbf{w} = \mathbf{U}\mathbf{v}, \tag{8}$$

where $\mathbf{v}$ is a $(KG \times 1)$ vector of the model parameters, $G < L$ is the model dimension and $\mathbf{U}$ is the parameter mapping matrix of dimension $(KL \times KG)$, which is selected as $\mathbf{U} = \{\tilde{u}_{lg}\mathbf{I}_K\}$, $l = 1 \dots L$, $g = 1 \dots G$, where $\mathbf{I}_K$ is the $K \times K$ identity matrix and

$$\tilde{u}_{lg} = \exp^{-2\pi j \frac{(l-1)(g-G/2)}{L}}, \; l = 1 \dots L, \; g = 1 \dots G. \tag{9}$$

Using this notation the basic algorithms are as follows:

$$\hat{\mathbf{v}}^{j}_{\text{LS(B)P}} = (\mathbf{U}^*\mathbf{X}^*\mathbf{X}\mathbf{U})^{-1}\mathbf{U}^*\mathbf{X}^*\Theta\{\mathbf{X}\mathbf{U}\hat{\mathbf{v}}^{j-1}_{\text{LS(B)P}}\}, \tag{10}$$

$$\hat{\mathbf{v}}^{0}_{\text{LSP}} = \hat{\mathbf{v}}_{\text{LS}} = (\mathbf{U}^*\mathbf{X}^*_{\text{t}}\mathbf{X}_{\text{t}}\mathbf{U})^{-1}\mathbf{U}^*\mathbf{X}^*_{\text{t}}\mathbf{s}_{\text{t}}, \tag{11}$$

$$\hat{\mathbf{v}}^{0}_{\text{LSBP}} = \hat{\mathbf{v}}_{\text{LSB}} = (NL/N_{\text{t}})(\mathbf{U}^*\mathbf{X}^*\mathbf{X}\mathbf{U})^{-1}\mathbf{U}^*\mathbf{X}^*_{\text{t}}\mathbf{s}_{\text{t}}. \tag{12}$$

Similarly, the OFDM versions of the selection rule (7) and the RLSP algorithm can be obtained as well.

Simulation results. We simulate a 1-by-4 SIMO system ($K = 4$) for a HIPERLAN/2 time-frequency slot of $N = 14$ symbols and $L = 64$ subcarriers (only 52 of them are used for data and pilots transmission). QPSK signalling and the HIPERLAN/2 “A” propagation channels are used for the desired signal and the interference. The transmitted signal is encoded according to the HIPERLAN/2 standard with a 3/4 code rate. Each packet contains 54 information bytes. Each time frequency slot includes two information packets and two preamble blocks of 52 binary pilot symbols. This simulation environment corresponds to the data rate of 18 Mbit/s. Packet Error Rate (PER) is used to evaluate the performance. Other simulation parameters are: SNR=20dB, $G = 12$, $I = 3$ and $J = 5$.

Figure 4 presents the PER curves averaged over 10^4 packets in the asynchronous scenario with $M = 1, 2, 3$ equal power interference components. One can see that the “crossing points” between LSP and LSBP exist for different structures of the asynchronous CCI and the re-configurable receiver outperforms the two conventional receivers across the board of SIR’s. The RLSP performance is close to the best performance of LSP and LSBP in the area of high and low SIR’s. The re-configurability gain in the “crossing point” area varies from 6.5 db to 1.5 dB depending on the scenario.

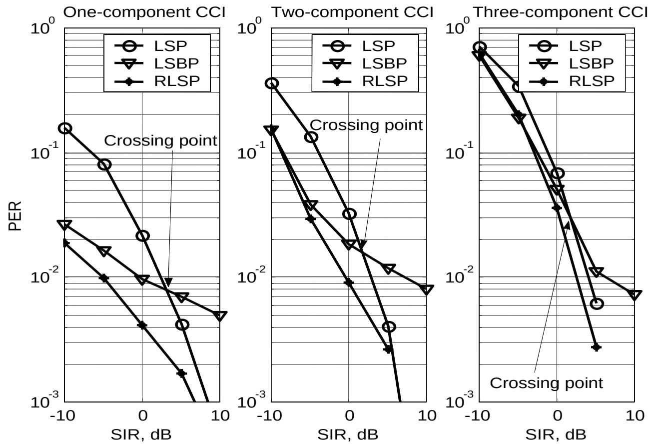

Fig. 4. PER in a HIPERLAN/2 environment

5. CONCLUSIONS

The problem of antenna array asynchronous interference cancellation is addressed. A re-configurable receiver is proposed, which is based on on-line selection of the initialization of the iterative semi-blind scheme with projections to the finite alphabet. It is shown by means of simulations in TDMA and OFDM environments that the proposed receiver significantly outperforms the existing semi-blind receivers.

6. ACKNOWLEDGMENT

The authors are grateful to Dr.D.R.Morgan for helpful advice. Part of this work has been done in the context of the IST-2000-30116 FITNESS project.

7. REFERENCES

[1] A.Paulraj, C.B.Papadias, “Space-time processing for wireless communications”, IEEE Signal Processing Magazine, vol. 14, n. 6, pp. 49-83, Nov. 1997.

[2] J.Karlsson, J.Heinegard, “Interference rejection combining for GSM”, in Proc. ICUPC, pp.433-437, 1996.

[3] E.Villier, L.Lopes, S.Aftelak, “On the application of uplink optimum combining to base station reception”, in Proc. IEEE 48th Veh. Technol. Conf., pp.747-752, Ottawa, 1998.

[4] M.C.Wells, “Increasing the capacity of GSM cellular radio using adaptive antennas”, IEE Proc. Communications, vol. 143, n.5, pp.304-310, 1996.

[5] P.E.Mogensen, P.Leth Espensen, K.I.Pedersen, P.Zetterberg, “Antenna arrays and space division multiple access”, in “GSM evolution towards 3rd generation systems”, Z.Zvonar, P.Jung, K. Kammerlander, eds., Kluwer Academic Publishers, 1999.

[6] A.M.Kuzminskiy, P.Strauch, “Space-time filtering with suppression of asynchronous co-channel interference”, in Proc. AS-SPCC, pp. 385-389, Lake Louise, Oct. 2000.

[7] A.M.Kuzminskiy, C.B.Papadias, “Asynchronous interference cancellation with an antenna array”, in Proc. IEEE 13th PIMRC, pp. 260-264, Lisbon, Sept. 2002.

[8] D.Bartolomé, X.Mestre, A.I.Pérez-Neira, “Single input multiple output techniques for Hiperlan/2”, in Proc. IST Mobile Communications Summit, Barcelona, Sept. 2001.

[9] A.M.Kuzminskiy, “Antenna array interference cancellation for OFDM based on parametric modeling of the weights”, in Proc. 35th Asilomar Conf. Sig., Syst. and Comp., Nov. 2001.