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Second-order asynchronous interference cancellation: Regularized semi-blind technique and non-asymptotic maximum likelihood benchmark ☆

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Abstract

An asynchronous interference cancellation problem is addressed where training and working intervals are available that contain the desired signal and arbitrary overlapping interference. A regularized non-iterative estimation of the antenna array coefficients is proposed which employs the autocorrelation matrix estimation as a weighted sum of the autocorrelation matrices estimated over the training and working intervals. A non-asymptotic second-order statistic maximum likelihood (ML) benchmark is developed, which is based on estimation of the structured covariance matrices over the training and working intervals for the Gaussian data model. It is shown by means of simulation in the TDMA and OFDM environments that the regularized semi-blind solution significantly outperforms the conventional estimators and demonstrates performance close to the proposed benchmark.

Keywords: Antenna array; Training and working data intervals; Asynchronous interference; Regularized semi-blind estimation; Non-asymptotic ML benchmark

1. Introduction

Conventional space–time equalization and interference cancellation techniques in wireless communications exploit known training symbols to estimate the weight vector of an antenna array or the propagation channel of the desired signal and space–time parameters of the interference [1–5]. The underlying assumption for these kinds of techniques is that the training data are reliable since the co-channel interference (CCI) completely overlaps with the training symbols of the desired signal. Normally, this is the case for synchronous CCI, which has the same time–frequency structure as the desired user. Asynchronous cells, packed transmission and other techniques lead to more complicated asynchronous or intermittent CCI scenarios [6–14], where the interference may partially overlap or not overlap with the training data of the desired signal.

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It is pointed out in [7] that stationary filtering can be exploited to enhance the desired signal and reject the asynchronous CCI if information data for the signal of interest are involved in the estimation of the weight coefficients together with the training data. Iterative semi-blind (SB) algorithms are used for cancellation of the asynchronous CCI in [7–14]. Although iterative receivers may be an effective solution to the considered problem, they are computationally expensive. The availability of training and working intervals with partially overlapping interference allows us to design a SB solution based on the second-order statistic, which involves data from both training and working intervals into estimation of antenna array coefficients. This simple non-iterative solution can be applied by itself or as initialization for different iterative schemes. More specifically, this technique does not require the number of interfering sources presented at the training and working intervals to be identified.

The main problem with this type of sub-optimal solution is to find how far they are from the potential performance in the class of algorithms based on the second-order statistic for the given amount of the training and information data. To address this problem, we consider the basic narrowband scenario with training and working time intervals containing the desired signal and arbitrary overlapping CCI and develop a non-asymptotic second-order statistic (Gaussian) ML benchmark. The basic idea of non-asymptotic benchmarking of solutions that are deemed to be ML has been developed in [15–17] and applied to different problems. The main idea stems from the straightforward observation that any solution to the ML problem is as good as the actual ML estimate in terms of accuracy, i.e., distance from the accurate matrix, if it generates the likelihood function (likelihood ratio, LR) value for the given data that exceeds the value of this function (ratio) generated for the same data by the accurate covariance matrix. For Monte-Carlo simulations with the known scenario, one can directly compare the LR value produced by optimization routine in question with the LR value generated by the true covariance matrix, and disregard the local solution as an outlier if the LR value of the actual covariance matrix is not exceeded. This benchmarking technique could be also applied to experimental (measured) data with some unknown underlying scenario. This is because the p.d.f. of the LR produced by the actual covariance matrix does not depend on scenario. It is exhaustively specified by the dimension of the problem and the number of data samples. In this case the optimized LR could be tested against some pre-calculated threshold selected in such a way that the LR generated by the accurate covariance matrix should exceed it with a given (high) probability.

In this paper we use the LR optimization approach for estimation of the structured covariance matrices over both training and working intervals in the asynchronous CCI scenario and propose to exploit the developed non-asymptotic benchmark for ad hoc estimators, like the one introduced in this paper, for both simulated and measured data.

In Section 2 we describe the data model and formulate the problem. A regularized SB solution is presented in Section 3. In Section 4 a non-asymptotic second-order statistic ML benchmark is developed in the asynchronous CCI environment. The simulation results in TDMA and OFDM scenarios are given in Section 5. Section 6 concludes the paper.

2. Data model and problem formulation

We consider the following narrowband data model of the signal received by an antenna array of K elements:

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

where $n = 1, \ldots, N$ is the time index; $\mathbf{x}(n) \in \mathscr{C}^{K\times 1}$ is the vector of observed outputs of an antenna array; $s(n)$ is the desired signal, $E\{|s|^2\} = p_s$, $E\{s(n_1)s^*(n_2)\} = 0$, $n_1 \neq n_2$, where $E\{\cdot\}$ denotes expectation; $u_m(n)$, $m = 1, \ldots, M$ are the $M < K-1$ components of CCI:

$$E\{u_m(n_1)u_m^*(n_2)\} = \begin{cases} p_m, & n_1 = n_2 \in \mathscr{N}_m, \\ 0, & n_1 = n_2 \notin \mathscr{N}_m, \\ 0, & n_1 \neq n_2. \end{cases} \tag{2}$$

$\mathscr{N}_m$ is the appearance interval for the mth interference component, $\mathbf{z}(n) \in \mathscr{C}^{K\times 1}$ is the vector of noise, $E\{\mathbf{z}(n)\mathbf{z}^*(n)\} = p_0\mathbf{I}_K$, $E\{\mathbf{z}(n_1)\mathbf{z}^*(n_2)\} = 0$, $n_1 \neq n_2$ and $\mathbf{h} \in \mathscr{C}^{K\times 1}$ and $\mathbf{g}_m \in \mathscr{C}^{K\times 1}$ are the vectors modelling linear propagation channels for the desired signal and interference. All propagation channels are assumed to be stationary over the whole data slot and independent for different antenna elements and slots. The desired signal,