Iterative Multiuser Detection for Complex Modulation Schemes

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Abstract — **For iterative multiuser detection and complex signal modulation, we show that the multiuser interference can become a rotationally variant random process in course of the iterations. Accounting for this property in the design of the multiuser interference suppression filters, significant performance gains can be reached compared to standard receivers.**

I. Introduction

Recently, in [1] and [2] it was reported that in DS–CDMA systems using *real* modulation schemes the multiuser interference in the received signal is a rotationally variant complex process and modified linear multiuser MMSE and ZF receivers were proposed, respectively, which utilize the rotational variance, i.e., the nonzero pseudocovariance matrix of the interference. So, higher signal–to–interference ratios can be reached compared to the corresponding conventional linear receivers designed for rotationally invariant interference. Employing standard *complex* modulation schemes the pseudocovariance matrix of the received signal is zero and a conventional linear receiver cannot be improved in this case. But, performing interference cancellation the residual interference becomes rotationally variant. In order to exploit this, we propose the application of a modified multiuser filter which takes into account the rotational variance arising during the iterations. We show that in this way significant performance gains are reached and that this concept is not restricted to multiuser detection but is also applicable to many other iterative schemes with decision feedback.

II. System Model

We consider a simplified discrete–time equivalent complex baseband transmission model which is described by $\boldsymbol{y} = \sum_{k=1}^{K} \boldsymbol{s}_k x_k + \boldsymbol{n} = \boldsymbol{S}\boldsymbol{x} + \boldsymbol{n}$. The vectors $\boldsymbol{y} = (y_1, \ldots, y_N)^T$, $\boldsymbol{n} = (n_1, \ldots, n_N)^T$, $\boldsymbol{x} = (x_1, \ldots, x_K)^T$, and $\boldsymbol{s}_k = (s_{1k}, \ldots, s_{Nk})^T$ represent the received signal, the additive rotationally invariant Gaussian channel noise, the complex data symbols of users $1, \ldots, K$, and the complex spreading sequence of user k, respectively. The matrix $\boldsymbol{S}$ is defined as $\boldsymbol{S} = (\boldsymbol{s}_1, \ldots, \boldsymbol{s}_K)$.

III. Iterative Multiuser Detection

To detect x_k in iteration $m \geq 1$, the soft estimate $d_\kappa^{m-1}, \kappa \neq k$, obtained for x_κ in iteration $m-1$ is used to subtract the remodulated signal $\boldsymbol{S}\boldsymbol{d}_k^m$, where $\boldsymbol{d}_k^m = (\ldots, d_{k-1}^{m-1}, 0, d_{k+1}^{m-1}, \ldots)^T$. In order to suppress the remaining multiuser interference before making a decision on x_k, $\boldsymbol{y}_k^m = \boldsymbol{S}(\boldsymbol{x} - \boldsymbol{d}_k^m) + \boldsymbol{n}$ is passed through a multiuser interference suppression filter.

Supposing that the total interference is a rotationally invariant random process, the standard MMSE filter $\boldsymbol{h}_k^m$ minimizing the mean–squared error $\mathcal{E}\{|x_k - (\boldsymbol{h}_k^m)^T \boldsymbol{y}_k^m|^2 | \boldsymbol{f}_k^{m-1}\}$, ($\boldsymbol{f}_k^{m-1} = (\ldots, f_{k-1}^{m-1}, 0, f_{k+1}^{m-1}, \ldots)^T$ represents the MMSE filter outputs of iteration $(m-1)$ of users $\kappa \neq k$) is

$$(\boldsymbol{h}_k^m)^T = \mathcal{E}\{x_k (\boldsymbol{y}_k^m)^H | \boldsymbol{f}_k^{m-1}\} (\mathcal{E}\{\boldsymbol{y}_k^m (\boldsymbol{y}_k^m)^H | \boldsymbol{f}_k^{m-1}\})^{-1}. \quad (1)$$

An analysis of the underlying assumption that the multiuser interference is rotationally invariant shows, that this holds for all users in iteration 1 as $\mathcal{E}\{(x_k - d_k^0)^2 | f_k^0\} = 0, \quad 1 \leq k \leq K$. However, cancelling the assumed interference caused by user k, we get for $m > 1$, QPSK modulation and the soft decision rule $d_k^m = \mathcal{E}\{x_k | f_k^m\}$

$$\begin{aligned}\mathcal{E}\{(x_k - d_k^m)^2 | f_k^m\} \\ = (d_{k,Q}^m)^2 - (d_{k,I}^m)^2 + 2\,\mathrm{j}[\mathcal{E}\{x_{k,I} x_{k,Q} | f_k^m\} - d_{k,I}^m d_{k,Q}^m],\end{aligned}$$

where I, Q stand for the inphase and quadrature component, respectively. The so–called pseudoautocorrelation $\mathcal{E}\{(x_k - d_k^m)^2 | f_k^m\}$ is only zero if (i) the absolute values of $d_{k,I}^m$ and $d_{k,Q}^m$ are equal and (ii) the soft decisions for the inphase and quadrature components are uncorrelated. In general, this will only be true at the beginning of the iterative decision process and hopefully at its end, i.e., when $d_k^m = x_k, \forall k$. But, in the intermediate stages a receiver which uses the rotational variance of the multiuser interference can perform better.

For exploitation of the pseudoautocorrelation, i.e., the correlation of $\boldsymbol{y}_k^m$ and $(\boldsymbol{y}_k^m)^*$, we suggest to apply a so–called widely linear filter $\tilde{\boldsymbol{h}}_k^m$ minimizing $\mathcal{E}\{|x_k - (\tilde{\boldsymbol{h}}_k^m)^T ((\boldsymbol{y}_k^m)^T, (\boldsymbol{y}_k^m)^H)^T|^2 | \tilde{\boldsymbol{f}}_k^{m-1}\}$ [3]. Here, we have $\tilde{\boldsymbol{f}}_k^{m-1} = (\ldots, \tilde{f}_{k-1}^{m-1}, 0, \tilde{f}_{k+1}^{m-1}, \ldots)^T$, where $\tilde{f}_k^{m-1} = (\tilde{\boldsymbol{h}}_k^{m-1})^T \tilde{\boldsymbol{y}}_k^{m-1}$ denotes the filter output for user k in iteration $m-1$ and $\tilde{\boldsymbol{y}}_k^{m-1} = ((\boldsymbol{y}_k^{m-1})^T, (\boldsymbol{y}_k^{m-1})^H)^T$ is the modified filter input. This optimization problem is equivalent to the standard Wiener approach with filter input $\tilde{\boldsymbol{y}}_k^m$ and is solved by

$$(\tilde{\boldsymbol{h}}_k^m)^T = \mathcal{E}\{x_k (\tilde{\boldsymbol{y}}_k^m)^H | \tilde{\boldsymbol{f}}_k^{m-1}\} (\mathcal{E}\{\tilde{\boldsymbol{y}}_k^m (\tilde{\boldsymbol{y}}_k^m)^H | \tilde{\boldsymbol{f}}_k^{m-1}\})^{-1}. \quad (2)$$

IV. Results

By analytical evaluation of the resulting signal–to–interference ratios as well as in simulations we find that significant gains are reachable by application of the modified MMSE filter. The performance gap to the standard MMSE filter rises with i) growing signal-to-noise ratio and/or ii) increasing system load. This is a consequence of the dominance of the rotationally variant residual multiuser interference for $m \geq 2$ compared to the channel noise in these cases. Especially for $K/N > 1$, i.e., when the multiuser interference cannot be suppressed completely by the conventional MMSE filter, large gains are achievable by exploitation of the rotational variance.

References

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