Analysis and Results on Optimized MIMO Detection with Threshold-Based Adaptive Cancellation

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***Abstract*— We present an analysis and improved results of a new algorithm for detection of the received signal of a encoded wireless MIMO system. The method is based on BLAST algorithm with successive interference cancellation which is now applied in an adaptive manner based on some threshold decision. Therefore, we extend reliability information on bits to symbol reliability. The principle idea of our method is not restricted to specific receiver designs but can be applied to any receiver with symbol interference cancellation. We use the threshold criterion to improve cancellation and present two methods how to obtain the optimum threshold. One is an exact analytical approach initially presented in this paper, and the second one is based on EXIT chart technique. To have a fair comparison, we also introduce a so called genie-threshold receiver analogous to the known genie detector. As a result, we obtain an SNR gain up to 1 dB. Furthermore, with a very low complexity iterative scheme, by applying our scheme we achieve a turbo cliff for a full rate 6×6 16-QAM system at 8.3 dB, which is to our knowledge unreached by MIMO systems with comparable low complexity.**

I. Introduction

In [2] and [3] it was shown that adaptive threshold-based cancellation can significantly improve the performance of a MIMO (multiple input multiple output) system and clearly outperforms both, MMSE equalization with ordered successive interference cancellation (OSIC) as well as MMSE equalization without OSIC. This can be achieved with practically no overhead in terms of computational complexity. The promising results and additional refinement of the detection algorithm give rise to further investigation and optimization of thresholds.

Our approach is based on a coded MIMO transmit model as depicted in Fig. 1 (Transmitter) and (as one example) the simple receiver in Fig. 2. But we point out that the presented analysis and design methods can be applied to any iterative or non-iterative receiver structure. In addition it is not restricted to single carrier solutions but can also be applied to MIMO-OFDM.

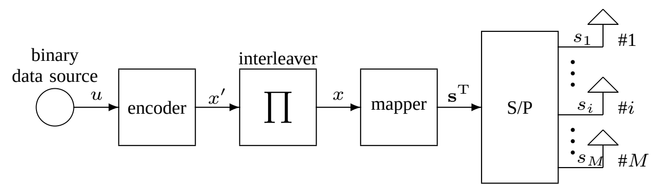

Fig. 1: Transmitter

The output of the MMSE channel equalizer can be written [2], [3] as

$$y_{d_\mu} = \underbrace{\widetilde{h}_{d_\mu,d_\mu} s_{d_\mu}}_{(A)} + \underbrace{\sum_{j\in\overline{\mathcal{D}_{d_\mu}}} \widetilde{h}_{d_\mu,j} \cdot s_j}_{(B)} + \underbrace{\widetilde{n}_{d_\mu}}_{(C)} + \underbrace{\sum_{j\in\mathcal{D}_{d_\mu}} \mathbf{w}_{d_\mu} \mathbf{h}_j \left(s_j - \hat{s}_j\right)}_{(D)} \ . \quad (1)$$

We have the following notation: μ is the number of the detection step and d_μ is the symbol number detected in this step. $\widetilde{h}_{i,j}$ is the attenuation factor for the channel from antenna j to antenna i remaining after channel equalization. $\mathbf{w}_{d_\mu}$ is the MMSE equalization vector for symbol d_μ and $\mathbf{h}_j$ is the channel response vector from antenna j to all receive

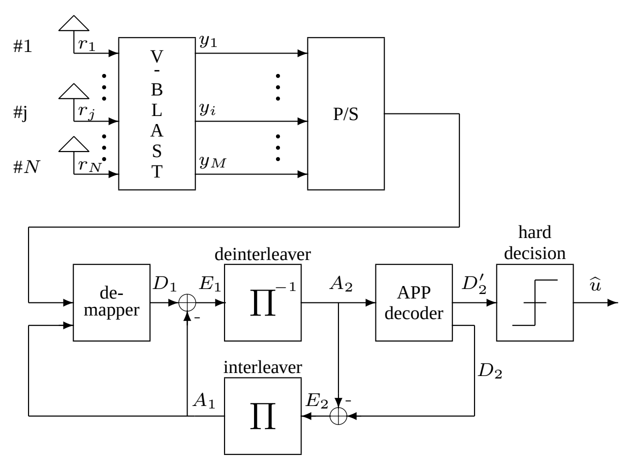

Fig. 2: Receiver structure

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antennas. $\widetilde{n}_{d_\mu}$ is the noise at the receiver filtered by the channel equalizer. $\hat{s}_j$ is an hard decided estimate on the actually transmitted symbol s_j. Terms *(B)*, *(C)*, and *(D)* are unknown to the receiver and are regarded as interfering noise. The variances of these three term can be calculated[1] for later MAP decoding. $\mathcal{D}_{d_\mu}$ contains all symbols that have been cancelled so far from the receive signal.

The idea of threshold-based adaptive cancellation is to cancel out only those symbols which are recognized to be correct with high probability. The log-likelihood value of a *bit* is known to be a possible reliability measure. Now, as a measure of reliability of a *symbol* we take the minimum absolute value of the log-likelihood values $\mathcal{R}\left(s\right)$ of the underlying bits of the symbol (see [2] for details) and apply the decision rule

- cancel the detected symbol $\hat{s}_{d_\mu}$ if $\mathcal{R}\left(y_{d_\mu}\right) > \mathcal{R}_{\text{th}}$
- do not cancel otherwise

It follows that the set $\overline{\mathcal{D}_{d_\mu}}$ does not only contain the number of the symbols that have not been detected yet, but also the number of those symbols that have been detected but rejected from cancellation due to threshold decision. The main task is to find the optimum $\mathcal{R}_{\text{th}}$. Tho methods to do so are presented in the next section.

II. Two methods to find the optimum threshold

A. The analytical approach

For the purpose of this extended abstract we just give a short derivation. For the moment assume that we have 2 transmit and receive antennas. Based on the decision rule, let the probability to cancel the first detected symbol to be p^*. Let the probability that this cancellation is advantageous be p^*_{C} and the probability that this cancellation leads to error propagation is p^*_{W}. Thus, $p^*_{\text{C}} + p^*_{\text{W}} = p^*$. Now the bit error ratio (BER) of the system with threshold-based adaptive cancellation is

$$P = \frac{1}{2}\left(P_1 + (1-p^*)P_2 + p^*_{\text{C}} P_{2,\text{genie}} + p^*_{\text{W}} P_{2,\text{wrong}}\right) \tag{2}$$

where P_1 is the BER of the bits of the first detected symbol only. P_2 is the BER of the bits of the second detected symbol if the first symbol is not deleted. $P_{2,\text{genie}}$ is the BER of the bits of the second symbol if the deletion of the first detected symbol was correct (i. e. genie cancellation as in [1]). $P_{2,\text{wrong}}$ is the BER of the bis of the second symbol if the first symbol was wrongly detected and its deletion leads to error propagation. In (2) $p^*_{\text{C}} = \int_{\mathcal{R}_{\text{th}}}^{\infty} p_{\text{C}}(\mathcal{R}_{\text{th}}) \mathrm{d}\mathcal{R}_{\text{th}}$, $p^*_{\text{W}} = \int_{\mathcal{R}_{\text{th}}}^{\infty} p_{\text{W}}(\mathcal{R}_{\text{th}}) \mathrm{d}\mathcal{R}_{\text{th}}$ and p^* depend on the chosen threshold $\mathcal{R}_{\text{th}}$, where p_{C} and p_{W} are the distributions of the minimum absolute L-values that lead to correct or wrong cancellation, respectively. To find the minimum of (2) we have to solve $\frac{\mathrm{d}P}{\mathrm{d}\mathcal{R}_{\text{th}}} = 0$ leading to

$$\alpha(\mathcal{R}_{\text{th}}, SNR) = \frac{p_{\text{C}}(\mathcal{R}_{\text{th}})}{p(\mathcal{R}_{\text{th}})} = \frac{1 - \frac{P_2}{P_{2,\text{wrong}}}}{1 - \frac{P_{2,\text{genie}}}{P_{2,\text{wrong}}}} = \beta(SNR)\ . \tag{3}$$

[1]This calculation is beyond the task of this extended abstract but will be given in the final paper.

The solution only depends on three fractions $\frac{p_{\text{c}}(\mathcal{R}_{\text{th}})}{p(\mathcal{R}_{\text{th}})}$, $\frac{P_2}{P_{2,\text{wrong}}}$, and $\frac{P_{2,\text{genie}}}{P_{2,\text{wrong}}}$. The right side only depends on the SNR whereas the left side depends on the SNR as well as on the threshold $\mathcal{R}_{\text{th}}$. Thus, the solution for the optimum threshold also depends on the SNR. However, to obtain $\mathcal{R}_{\text{th}} = \alpha^{-1}(\beta)$ a lookup table can be used. In similar ways, this scheme can be extended to systems with more than 2 antennas resulting in terms that depend on more fractions[2].

B. The mutual information approach

Recently, the EXIT chart technique has been discovered to be an excellent designing tool for MIMO systems (e.g. [4]). To reduce BER for the very first pass of the iterative structure, it is necessary to maximize the extrinsic information I_E for none a priori information $I_A = 0$. EXIT chart analysis shows that the range of the optimum threshold for a wide range of different systems only varies in the range of about 1 to 1.4 and is interestingly nearly independent of the SNR. In addition, the performance of systems is practically the same for any choice of threshold in the mentioned range. Therefore, it is possible to use a fixed threshold for all kind of system constellations.

III. Simulation results

In Fig. 3 we present the comparison of a regular MMSE-BLAST with and without OSIC, the genie-threshold system and our proposed new threshold-based adaptive cancellation with $\mathcal{R}_{\text{th}} = 1.2$. Note, that this approach needs no iteration. Our scheme outperforms both, OSIC as well as no cancellation, though it is less complex than full cancellation. The figure also shows that the diversity slope obtained by the genie case is still not reached due to error propagation. In Fig. 4 we show that it is possible to achieve a turbo cliff SNR of 8.3 dB. Note, that we only iterate over the demapper and the outer decoder (see Fig. 2) and do not feed back any information to the MIMO detection stage.

[2]This is also subject to the final paper.

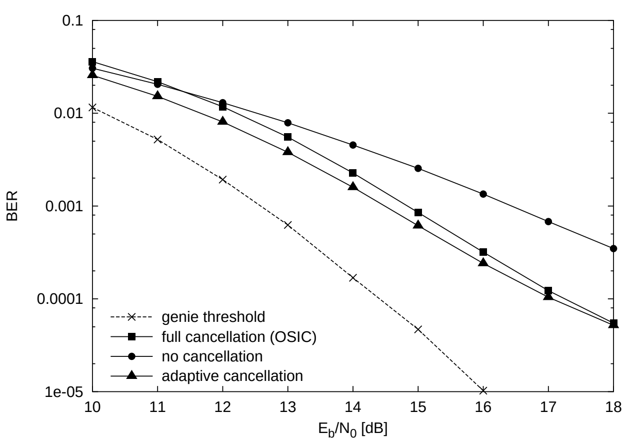

Fig. 3: BER for $M = N = 5$, 16-QAM, MMSE, $\mathcal{R}_{\text{th}} = 1.2$

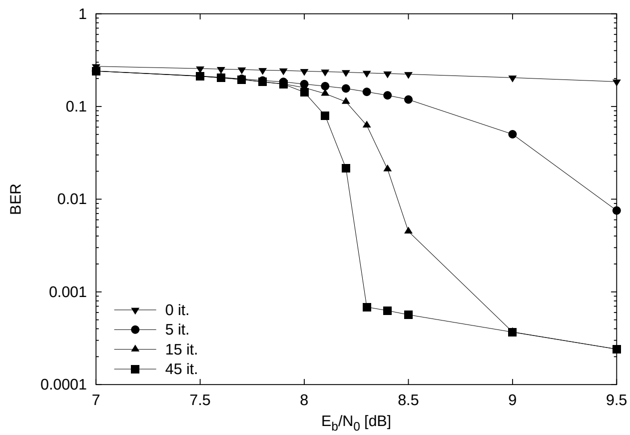

Fig. 4: BER for iterative $M = N = 6$, 16-QAM, MMSE, $\mathcal{R}_{\mathrm{th}} = 1.2$

IV. CONCLUSION

We presented two methods how to obtain the optimum threshold for adaptive threshold-based cancellation in MIMO systems. Simulation results show a remarkable gain in performance. In the final paper we derive the given formulas, present the used EXIT chart design technique in detail, and present some more results also on other iterative schemes.

REFERENCES

[1] S. Bäro, G. Bauch, A. Pavlic, and A. Semmler, "Improving BLAST performance using space-time block codes and turbo decoding," in *IEEE Global Telecommunications Conference 2000 (Globecom)*, November 2000, pp. 1067–1071.

[2] A. Boronka, D. Efinger, and J. Speidel, "Improving MIMO detection by L-value analysis and adaptive threshold based cancellation," in *IEEE Global Telecommunications Conference 2003 (Globecom)*, San Francisco, USA, December 1-5, 2003.

[3] A. Boronka, T. Rankl, and J. Speidel, "Iterative nonlinear detection of MIMO signals using an MMSE-OSIC detector and adaptive cancellation," in *5th International ITG Conference on Source and Channel Coding*, Erlangen, Germany, January 14-16, 2004 submitted for publication.

[4] G. Bauch and F. Schreckenbach, "How to obtain turbo gains in coherent and non-coherent orthogonal transmit diversity," in *14th International Symposium on Personal, Indoor, and Mobile Radio Communications PIMRC 2003*, vol. 2, Beijing, China, September 7-10, 2003, pp. 1988–1992.