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Turbo-deflation: implementation and performance

O. Benrhouma, S. Houcke and A. Bouallegue

Proposed is a new blind method exploiting transmit diversity and allowing the transmission of digital communication over a frequency selective fading channel. The scheme, called turbo-deflation, uses two transmit antennas and K ($K > 2$) received antennas. It is an iterative process based on the deflation procedure and the turbo decoding principle. This blind approach, which means that the receiver does not need any training sequence, could be used for several communication systems such as for underwater communications.

Introduction: Blind source separation has been the subject of research during the last decade [1–3], one of the most active areas connecting signal processing and communication networks. It consists in extracting emitting symbols of independent sources from only an observed linear mixture of them. In this Letter, we propose a new blind method (without training sequence) allowing exploiting of the emission diversity in the numerical communication context on multipath channels.

In the following, our communication system has two transmit antennas and K ($K > 2$) received antennas over a frequency selective channel. Denote by $y_p(t)$ the contribution in $y(t)$ of the signal emitted by antenna number p . Thus $y(t)$ can be seen as a linear mixture of two sources $y(t) = y_1(t) + y_2(t)$. In the telecommunication framework, $y_p(t)$ ($p = 1, 2$) is modelled as follows: $y_p(t) = \sum_m s_p(m)h_p(t - mT)$, where $(s_p(m))_m$ is an IID sequence of discrete Q-PSK symbols, T is the symbol period and h_p denotes the impulse response of the channel relative to source p . At the receiver side, y is observed through an array of K sensors and thus $y(t)$ and $h_p(t)$ are $K \times 1$ vector-valued. Simply, we propose that the two transmit antennas send the same information. $S_1(n) = (s_1(nN), \dots, s_1(nN + N - 1))^T$ and $S_2(n) = (s_2(nN), \dots, s_2(nN + N - 1))^T$ have the following relation: $S_2(n) = \Pi_N S_1(n)$, where Π_N is an $N \times N$ pseudo-random interleaver. We also assume that the channel is stationary over the duration NT .

At the receiver, we estimate the data sent by each antenna using a blind source separation approach. To extract the sources, we use the deflation approach [3] that is based on the minimisation of a contrast function. This Letter proposes a method called turbo-deflation based on the deflation approach and on the turbo decoding principle.

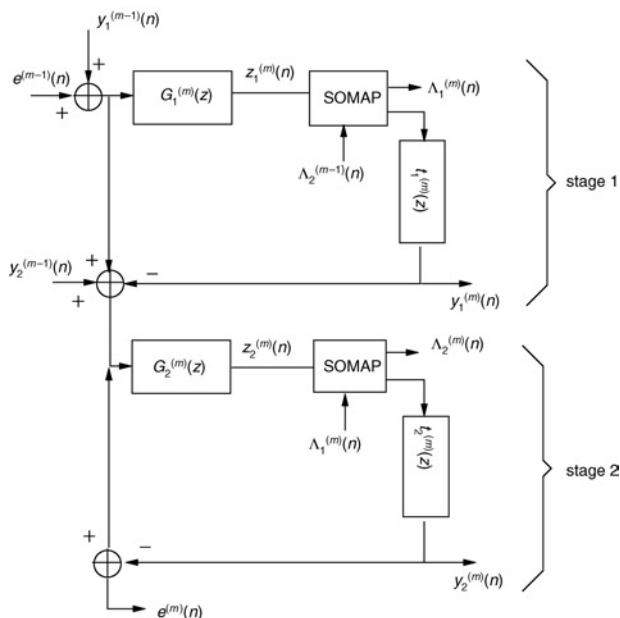


Fig. 1 Iteration m of turbo deflation

Turbo-deflation description: Fig. 1 shows the turbo-deflation principle at iteration m . While having two sources, one iteration of our method is split into two stages. Each stage estimates symbols emitted by one source. Furthermore, as the two sources send the same symbols but interleaved, we compute from the first extracted source an extrinsic

information that is used as *a priori* information for the estimate of the second one.

At stage k (at the output of $G_k^{(m)}(z)$ (see Fig. 1), we obtain, $Z_k^{(m)}(n) = (z_k^{(m)}(nN), \dots, z_k^{(m)}(nN + N - 1))^T$, an estimate up to a multiplicative factor and a delay of the symbols of one of the sources.

We now describe in detail the estimation of $S_1(n)$ that we call ‘SOMAP’ in Fig. 1 for SOft MAPping. We consider Q-PSK symbols in this Letter. Therefore, we treat separately their real and imaginary part. The problem now consists in estimating a vector $U_1(n) = [\mathcal{R}(S_1(n)), \mathcal{I}(S_1(n))]^T$ of size $2N \times 1$ with value in $\{+1, -1\}$, where $\mathcal{R}(x)$ (respectively, $\mathcal{I}(x)$) denotes the real (respectively, imaginary) part of x . Let us consider the iteration m . The estimate $\hat{U}_1^{(m)}(n)$ of $U_1(n)$ is obtained by (for details refer to [4]):

$$\hat{U}_1^{(m)}(n) = \mathbb{E}[U_1(n)/L_1^{(m)}(U_1(n))] = \tanh\left(\frac{L_1^{(m)}(U_1(n)|Z_1^{(m)}(n))}{2}\right)$$

where $L_1^{(m)}(U_1(n))$ is the information *a priori* of $U_1(n)$ and $L_1^{(m)}(U_1(n)|Z_1^{(m)}(n))$ is the *a posteriori* log-likelihood ratio of $U_1(n)$. From $Z_1^{(m)}(n)$, we estimate $L_1^{(m)}(U_1(n)|Z_1^{(m)}(n))$ as follows: $L_1^{(m)}(U_1(n)|Z_1^{(m)}(n)) = L_1^{(m)}(U_1(n)) + \Lambda_1^{(m)}(n)$, where $\Lambda_1^{(m)}(n)$ is the extrinsic information estimate of the sequence $U_1(n)$. $Z_1^{(m)}(n)$ may be viewed as the output of an equivalent AWGN channel. Thus, we have: $\Lambda_1^{(m)}(n) = [2\mathcal{R}(Z_1^{(m)}(n))/\hat{v}_{1,m}^2, 2\mathcal{I}(Z_1^{(m)}(n))/\hat{v}_{1,m}^2]^T$ where $\hat{v}_{k,m}^2$ is an estimate of the variance of the noise. $L_1^{(m)}(U_1(n))$ is the estimate at iteration m of the *a priori* information of $U_1(n)$. At stage 2 of the previous iteration, we computed $\Lambda_2^{(m-1)}(n)$ from $Z_2^{(m-1)}(n)$. As $S_2(n)$ is assumed independent of $S_1(n)$, we can use the extrinsic information $\Lambda_2^{(m-1)}(n)$ of source 2 as *a priori* information for source 1. Using the relation between the two sources, we have:

$$L_1^{(m)}(U_1(n)) = \begin{pmatrix} \Pi_N^{-1} & 0_N \\ 0_N & \Pi_N^{-1} \end{pmatrix} \Lambda_2^{(m-1)}(n)$$

where 0_N is an $N \times N$ matrix of zeros. At the next stage, we proceed in the same way for the estimation of $S_2(n)$. We then compute the conditional log-likelihood $L_2^{(m)}(U_2(n)|Z_2^{(m)}(n))$ of $U_2(n) = [\mathcal{R}(S_2(n)), \mathcal{I}(S_2(n))]^T$. The extrinsic information $\Lambda_2^{(m)}(n)$ is computed as depicted above where the subscript \cdot_1 should be replaced by \cdot_2 . Finally, the interleaved version of the extrinsic information computed during the previous stage is used as *a priori* information:

$$L_2^{(m)}(U_2(n)) = \begin{pmatrix} \Pi_N & 0_N \\ 0_N & \Pi_N \end{pmatrix} \Lambda_1^{(m)}(n)$$

Results: In this Section, we consider a mixture of two Q-PSK sources. A pseudorandom interleaver of size $N = 1000$ is used. The considered contrast function is the Godard criterion and $G_k^{(m)}(z)$ is obtained as follows: $G_k^{(m)}(z) = \text{ArgMin}(1/N) \sum_{n=0}^{N-1} (|z_k^{(m)}(n)|^2 - 1)^2$. The filter G has a fixed number of taps set to 5 and the minimisation is done by a Newton algorithm. We now specify the propagation model. The excess bandwidth factors are all equal to 0.2, the propagation channel results from the superposition of three paths (the delays and directions of arrival and directions of departure are uniformly chosen in, respectively, $[0; 3T]$ and $[0; 2\pi]$, the attenuation of the path follows a Rayleigh distribution, the distance between the transmitted (respectively, received) antennas is $\lambda/2$ where λ is the wave length of the signal). The number of sensors is set to $K = 3$. Finally, the duration of y is set to $1000T$. All the following results have been averaged over 1000 trials, where the channel and the symbol sequences are randomly generated for each new trial. The method is tested in a noisy context. The noise is assumed Gaussian, complex, temporally and spatially white with zero mean.

To illustrate the behaviour of our method, we first consider that the sources are mutually independent: information obtained from the extraction of source 1 cannot be used for the estimation of source 2. Performance is measured by the residual bit error rate (BER) at the output of the iterative deflation procedure. Fig. 2 shows the BER for the first extracted source at iterations 1, 3 and 7. We observe that BER increases with the number of iterations. This can be explained by the fact that in a noisy context, the deflation procedure introduces error propagation. Indeed, at each deflation stage the subtraction of the contribution of the extracted source from the observed signal increases the noise level. Of course, this affects the performance of our method.

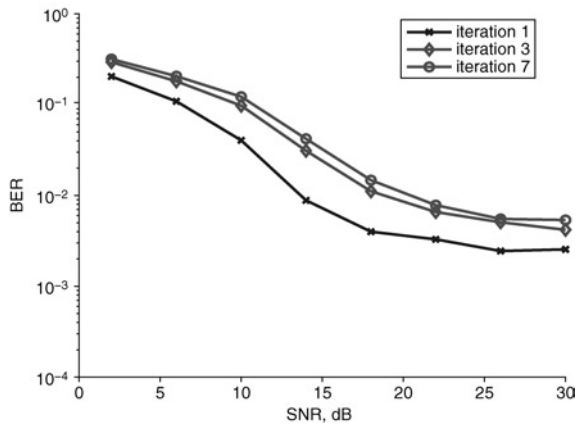


Fig. 2 Iterative deflation performance: BER against SNR of first extracted source

We now consider the case where the second source transmits an interleaved version of the symbols emitted by the first antenna. A pseudorandom interleaver of size $N = 1000$ symbols is used. To evaluate the performance of our method, we measure bit error rates computed from the sequence estimated at iterations 1, 3, 5 and 7. Results are shown in Fig. 3. We observe that the more iterations, the smaller the BER. Although, the iterative deflation procedure also introduces error propagation, here the exploitation of transmit diversity allows us to improve the estimation of symbols from one iteration to another.

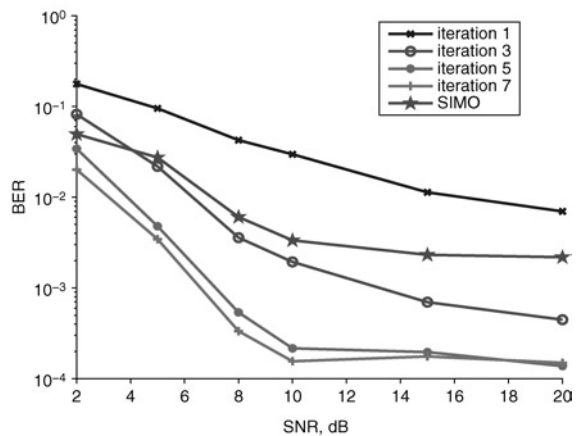


Fig. 3 Turbo deflation performance: BER against SNR

As we did not find in the literature any blind transmit diversity method over frequency-selective fading channel and as we need a point of comparison, we compare our method with the following scenario: one single antenna transmitting the sequence $S_1(n)$ over the same propagation channel (equivalent to a SIMO model) but with a power equal to the sum of powers used on each transmit antenna. Results are also presented in Fig. 3, demonstrating that our method outperforms the performance obtained by a single antenna using twice as much power. Thus, it is relevant to use transmit diversity in a blind communication scheme.

Conclusions: We have developed a new method allowing us the estimation of symbols emitted by the sources of a MIMO system. We provide simulations to illustrate the behaviour of our method and show that it is relevant to consider transmit diversity for blind communications over a frequency-selective fading channel. For instance, a potential application could be acoustic transmissions. Note that the method can be easily extended to more than two transmit antennas.

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