Experimental Evaluation of Unsupervised Channel Deconvolution for Wireless Multiple-Transmitter / Multiple-Receiver Systems

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We present an over-the-air demonstration of unsupervised (blind) multiple-input / multiple output (MIMO) channel deconvolution. The results were obtained in an indoor multiple antenna (BLAST) [1] context. A suitable unsupervised MIMO technique [2] was used in order to avoid the effective reduction of spectral efficiency caused by the use of channel training. To the best of our knowledge, this may be the first reported experiment of successful over-the-air unsupervised MIMO deconvolution.

Introduction: The Bell-labs LAyered Space-Time (BLAST) architecture [1] uses multiple antenna elements at both transmitter and receiver to provide high capacity wireless communications in a rich scattering environment. The theoretical MIMO channel capacity increases roughly linearly with the number of Tx / Rx antennas [1].

Receiver algorithms typically require explicit knowledge of the MIMO channel response, which in turn requires the use of training or pilot sequences that limit the system's spectral efficiency. To avoid the training overhead, unsupervised (blind) alternatives should be sought. A large number of so-called blind source separation (BSS) techniques for MIMO channels can be found in the literature [3]. In this work, our goal has been to demonstrate over-the-air the applicability of such techniques to wireless BLAST-type systems.

Due to their highly non-linear objective functions, BSS techniques may often converge to false (undesired) solutions. For this reason, we have focused on a recently introduced technique [2], which was theoretically shown to be globally convergent to a setting that recovers all the input signals. The technique is called the Multi-User Kurtosis (MUK) algorithm and it is based on a deflation-type optimisation of a cost function that contains the output signals' fourth-order cumulants under second-order (whiteness) constraints.

For the purposes of this work, we used a MIMO narrow-band wireless test-bed that we have built for verification and performance evaluation of different algorithms related to BLAST architectures (see [4, 5]). We use bit-error rate (BER) as a performance metric, and we compare the MUK scheme against well-known trained solutions. As shown in the following, our experimental results suggest the applicability of BSS techniques to real MIMO systems.

Baseband processing: The baseband received vector is modelled as

$$\mathbf{r}(k) = \mathbf{H}\,\mathbf{a}(k) + \mathbf{n}(k) \qquad (1)$$

$\mathbf{H}$ is a N x M complex-entry matrix that corresponds to the narrowband MIMO channel response. $\mathbf{a}(k)$ is a complex input (data) M x 1 vector and $\mathbf{n}(k)$ is the N x 1 additive white Gaussian noise (AWGN) impairment, all corresponding to the k^{th} time sample. In order to recover input vector $\mathbf{a}(k)$, $\mathbf{r}(k)$ is filtered by a N x M "spatial equaliser" $\mathbf{W}$ which results in output vector $\mathbf{z}(k) = [z_1(k)\ldots z_M(k)]^{\text{T}}$ as

$$\mathbf{z}(k) = \mathbf{W}^{\text{T}}\,\mathbf{r}(k) = \mathbf{G}^{\text{T}}\,\mathbf{a}(k) + \mathbf{n'}(k) \qquad (2)$$

$\mathbf{G}$ is the M x M global response matrix, $\mathbf{n'}(k) = \mathbf{W}^{\text{T}}\,\mathbf{n}(k)$ and T denotes transpose. The MUK algorithm [2] first updates $\mathbf{W}(k)$ in the direction of the MUK criterion's gradient as

$$\mathbf{W'}(k+1)=\mathbf{W}(k) - \mu\ \mathbf{r}^*(k)\,\mathbf{Z}(k) \qquad (3)$$

where $\mathbf{Z}(k) = [|z_1(k)|^2\ldots|z_M(k)|^2]^{\text{T}}$, and μ is a small step size. Then, a Gram-Schmidt orthogonalisation of the columns of $\mathbf{W'}(k+1)$ is performed, resulting in $\mathbf{W}(k+1)$ whose columns are orthogonal (see [2]). Note that before the algorithm is run, the received signal $\mathbf{r}(k)$ needs to be pre-whitened (resulting in a unitary $\mathbf{H}$).

The MUK algorithm is executed on a data set which has L symbols, and corresponds to a frame which is communicated over the air. All the L symbols are information bearing, i.e., no portion of the frame is dedicated to a training sequence. In order to improve the results of the adaptation in (3), the above algorithm can be re-run several times using the same data set, i.e., the same frame, before the detection of the transmitted data is performed. For the particular implementation of the MUK algorithm in this paper, we use $\mu = 0.04$. Also, we perform four re-runs to get the matrix $\mathbf{W}$.

Narrowband MTMR wireless test-bed: The radio frequency (RF) front-end of the test-bed consists of an antenna array, and the corresponding array of analog RF transmitters and receivers. The carrier is at 1.95GHz and the signal bandwidth is limited to 30KHz. The baseband digital signal processing is executed using a DSP multiprocessor system: Pentek 4285. It consists of eight Texas Instrument's TMS320C40 DSPs, offering a total processing power of 400MIPS. The interfacing towards the baseband is realised using a system of multi-channel A/D (Pentek 4275) and D/A (Pentek 4253) converters, respectively. The maximum sampling rate per baseband channel is 100KHz.

Experimental results: We present results that correspond to non-line-of-site indoor over-the-air trials. We use $M = 4$ transmit and $N = 6$ receive antennas and uncoded QPSK modulation on each antenna. The symbol frames are organised as follows. Symbols 1 to 16 are used for synchronisation, i.e., frame and symbol timing recovery (this part of the frame is identical for all sub-streams). K symbols compose a training sequence, which is used for estimation of the MIMO channel response (between the sub-streams, the sequences are mutually orthogonal and with equal transmit power). No training is used for the MUK, thus increasing its effective throughput.

For the trained receivers, we observe the performance for training lengths $K = 10$ and 20 symbols. The frame length is set to $L = 100$ or 200 *s*ymbols, i.e., 4 or 8 ms, respectively. The channel estimation is performed at the beginning of the frame, and no channel tracking is executed later, i.e., it is assumed that the channel is static during the frame period. This assumption is valid for indoor MIMO channels (mostly pedestrian speeds). The MUK adaptive algorithm uses all 100 or 200 symbols for the adaptation and, as stated earlier, it does not use a training sequence ($K_{\text{muk}} = 0$).

In Figure 1 we show the eye diagram per sub-stream after the 4-th re-run of the MUK. We also present the squared error between z_p (output of the MUK algorithm for $L = 200$) and transmitted data a_p (p=1,…,4), after the outputs are properly re-ordered. From the results we observe the ability of the MUK scheme to perform fully blind channel deconvolution and source separation. Figure 2 presents the CDF of the BER estimate (measured per frame) obtained from our over-the-air indoor trials. Measured SNR is approximately 12 dB. From the results, it is clear that the MUK algorithm does not fail during these real communication sessions. The trained receivers (linear minimum mean squared error (MMSE) and non-linear V-BLAST [4]) do perform better at this SNR, but the MUK algorithm is able to follow the performance of the MMSE detector. Note that the MUK algorithm increases the throughput by 20% (for $L = 100$ and $K = 20$) and / or 10% (for $L = 100$ and K=10), at the price of somewhat higher BER. We have also run the system for lower SNR's: both linear solutions (MUK and MMSE) outperformed the uncoded V-BLAST receiver at SNR's below 2 dB.

Conclusion: In this paper, we validated the excellent performance of the MUK algorithm in an over-the-air wireless MIMO environment. Based on the results, we believe that blind approaches can be successfully used in true MIMO wireless systems.

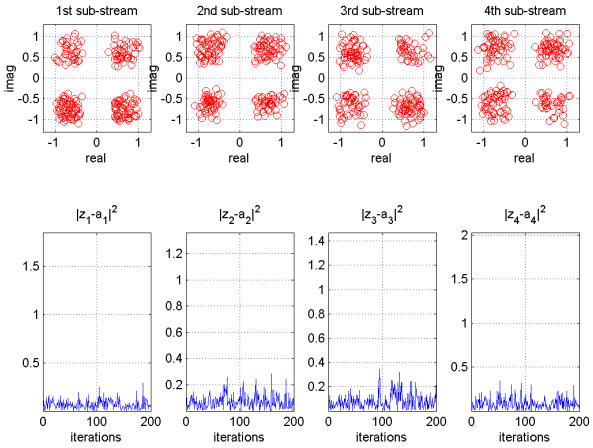

Fig. 1. The eye diagram and squared error per sub-stream, after the fourth re-run (L = 200, M=4, N= 6, over-the-air trials, SNR~12dB.)

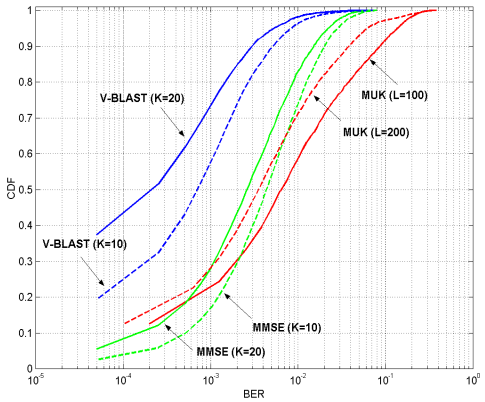

Fig. 2. CDF of BER, M=4, N=6, over-the-air trials, SNR~12dB

References

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