List-Sphere Decoder with Channel Matrix Ordering for MIMO Systems

Luis G. Barbero and John S. Thompson
Institute for Digital Communications - University of Edinburgh
E-mail: {l.barbero, john.thompson}@ed.ac.uk

Abstract— **This paper analyzes the effect the channel matrix ordering has on the list-sphere decoder (LSD) when it is applied to the detection of multiple input-multiple output (MIMO) systems that use space-time coding based on bit-interleaved coded modulation (BICM).**

We consider a MIMO system with M transmit and N receive antennas denoted as $M\times N$, with $N \geq M$, used for the transmission of frames of K_b bits. At the transmitter, the information bits are encoded, using an off-the-shelf turbo code, interleaved and mapped to P-quadrature amplitude modulation (QAM) symbols, forming a sequence of $K_s = K_b/\log_2 P$ symbols. The sequence of symbols is split into M substreams and blocks of K_{ch} symbols, representing a channel use, are transmitted in parallel from each one of the M antennas. The N-vector of received symbols is written as $\mathbf{r} = \mathbf{Hs}+\mathbf{n}$; where $\mathbf{s}$ is the M-vector of transmitted symbols with $\mathrm{E}[|s_i|^2] = 1/M$, a block Rayleigh fading channel is represented by the $N\times M$ matrix $\mathbf{H}$, with independent elements $\sim \mathcal{CN}(0,1)$, and $\mathbf{n}$ is the N-vector of independent additive white Gaussian noise (AWGN) samples $\sim \mathcal{CN}(0,\sigma^2)$ with $\sigma^2 = N_0$.

The detection and decoding of the symbols at the receiver can be done using the architecture presented in [1], where an inner and an outer decoder exchange extrinsic information iteratively. The inner decoder consists of a list version of the sphere decoder (SD) [2]. The LSD-C obtains a list of the C lattice points $\mathbf{Hs}$ closest to $\mathbf{r}$. That list of candidates is then used to calculate the a-posteriori log-likelihood ratio (LLR) ratios, i.e. L_D-values, of the coded bits, considering the a-priori L_A-values obtained from the outer decoder and the extrinsic L_E-values from the LSD, following $L_D(x_k|\mathbf{r}) = L_A(x_k) + L_E(x_k|\mathbf{r})$; where x_k represents the k-th coded bit of the transmitted frame. Details of the calculation of $L_D(x_k|\mathbf{r})$ can be found in [1]. For the outer decoder, a standard turbo decoder is used.

This paper shows how the ordering of the columns of the channel matrix can reduce the complexity of the LSD. Three different ordering methods have been studied. Initially, a vertical-Bell Labs layered space time (V-BLAST) optimal ordering has been considered using both the zero forcing (ZF) and the minimum mean-square error (MMSE) criterion. In addition, a low-complexity ordering has been considered, consisting of only one iteration of the original V-BLAST-ZF ordering (norm ordering).

The performance and complexity of the LSD have been evaluated using Monte-Carlo simulations. Frames of $K_b =$ 8192 bits have been transmitted in a 4×4 system with 16-QAM modulation with $K_{ch} = 16$ symbols. The LSD obtains $C = 16$ candidates and using the Schnorr-Euchner enumeration as opposed to the Pohst one used in [1]. A rate $r = 1/2$ turbo code of memory 2 with two recursive systematic convolutional (RSC) codes with generator polynomials $(7,5)$ has been used together with pseudo-random interleavers. One complete iteration at the receiver consists of one detection iteration (d) and two turbo iterations (t). The LSD is run only once at the beginning of the detection process and a Max-Log approximation has been used for the calculation of the L_D-values.

The results are shown in Fig. 1. It can be seen how the V-BLAST-MMSE ordering affects the performance of the LSD as in the uncoded case, while the rest of the orderings achieve the same performance as the no ordering case. However, the degradation decreases if we perform more iterations at the receiver (results for 1 and 4 complete iterations at the receiver are shown). In terms of complexity, we see how the V-BLAST-MMSE ordering greatly reduces the number of operations, especially in the region of interest ($E_b/N_0 < 15$ dB). At low E_b/N_0, the complexity actually decreases due to the effect the noise has in the ordering process. It can also be seen how the norm ordering achieves a significant percentage of the complexity reduction of the V-BLAST-ZF ordering by performing only one ordering iteration.

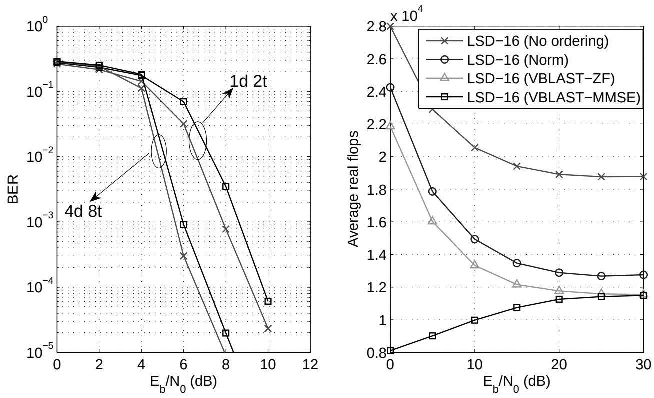

Fig. 1. Performance and complexity of the LSD-16 with channel matrix ordering in a 4×4 system with 16-QAM modulation as a function of the signal to noise ratio per bit (E_b/N_0).

References

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[2] M. O. Damen, H. E. Gamal, and G. Caire, "On maximum-likelihood detection and the search for the closest lattice point," *IEEE Trans. Inform. Theory*, vol. 49, no. 10, pp. 2389–2402, Oct. 2003.