Improving the Reliability of Receivers for 5G Networks

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***Abstract*—Multiple-input multiple-output (MIMO) systems with a large number of antennas are imperative for future wireless networks. The reliability of receivers in such networks depends critically on the detection algorithm used. The existing detection algorithms for such systems can be grouped into three categories viz. neighborhood search algorithms, lattice reduction based algorithms and sparse recovery based algorithms. Although these algorithms have reasonably low complexities, their reliability performance needs further improvement. In this paper we propose a novel structure for realizing significantly improved error performances by using existing algorithms as tools.**

I. Motivation

Large/massive multiple-input multiple-output (MIMO) systems are considered to be a key technology for meeting the high data rate demands of 5G wireless networks [1], [2]. The reliability i.e. bit/frame error rate (BER) performance of such systems depends critically on the detection algorithm used in the receiver. To address this problem, several low complexity detection algorithms have been proposed in the literature. These algorithms can be broadly classified as neighborhood search (NS) algorithms [3]–[5], element based lattice reduction (ELR) algorithms [6] and sparse error recovery (SER) based algorithms [7]. The NS algorithms begin with an initial guess, generate a neighborhood around the initial guess and replace it with the best solution in the neighborhood. Their performance is dependent on the accuracy of the initial guess and the size of the neighborhood. The ELR based algorithms condition the channel matrix and use it on a low complexity detector say zero forcing (ZF) or minimum mean square error (MMSE) or successive interference cancellation (SIC). SER based algorithms initialize with a solution (similar to neighborhood search algorithms), find the erroneous locations and correct them.

Although these algorithms have low complexity, their reliability performance, in terms of BER, needs improvement if the true capacity potential of large MIMO systems is to be realized. In this paper we conjecture that if these algorithms can be suitably combined, the limitations of some can be overcome, to some extent, by another algorithm. Thus a complementary approach can be used to enhance the error performance.

This work was supported by Tata Consultancy Services Limited.

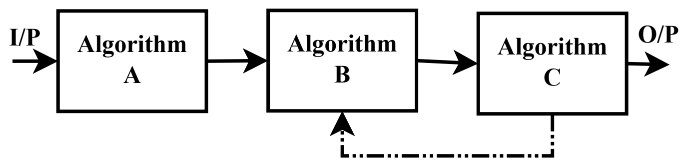

Fig. 1. Complementary approach where the output of one algorithm is used by other in an open (without feedback) or a closed loop (with feedback).

II. Detection Problem

The objective of a detection algorithm is to find the vector from the set of all possible transmit vectors which minimizes the Euclidean distance. Mathematically, this is stated as

$$\hat{X} = \underset{X \in \Omega^{N_t}}{\operatorname{argmin}} \|Y - \mathbf{H}X\|^2 \tag{1}$$

and is known as maximum likelihood (ML) detection. Here $\|\cdot\|$ denotes L_2 norm, $X \in \mathbb{C}^{N_t \times 1}$ is the transmit vector with each $x_i \in \Omega$ where Ω is a set of M complex symbols, $\mathbf{H} \in \mathbb{C}^{N_r \times N_t}$ is the channel matrix with each coefficient $h_{ij} \in \mathcal{CN}(0, 1)$.

The problem in (1) is NP-hard and cannot be solved exactly even for small number of antenna pairs. Hence practical systems seek an approximate solution which provides a reasonable BER, in an average sense.

III. Solution Approach

The proposed solution approach is depicted in Fig. 1 where three blocks are cascaded together. The vector received at the receiver is the input to the first block and the vector detected by the receiver is the output of the third block. While algorithm A denotes the detection algorithm used for initialization, algorithms B and C are two other detection algorithms. The output of algorithm A is used to initialize algorithm B and the output of algorithm B is used to initialize algorithm C. All the three algorithms A, B and C need to be low complexity algorithms. The goal is to find the right choices for A, B and C such that final reliability achieved is much better than either of them. Since we are using only low complexity algorithms, the overall complexity continues to be low.

Ideally, it is desired to choose algorithms B and C such that the errors likely to be undetected by B are detected by C and the errors likely to be undetected by C are already detected by B. Hence we refer to the proposed detection algorithm as Complementary Detection (CD) algorithm.

We proposed to use ELR based algorithm as algorithm A. This is because an ELR based algorithm is used to condition the channel matrix and hence it is required only once, every time the channel matrix changes. We propose to use two versions of A i.e. ELR based MMSE and ELR based SIC. Now we need to make suitable choices for B and C. For algorithms B and C we would like to select algorithms which provide better BER performance than the algorithm chosen for A. Hence we propose to use SER and NS as candidates for algorithms B as well as C. Thus, one may use SER for algorithm B and NS for algorithm C or vice versa.

It may be worth noting that the proposed complementary approach is novel because conventional detection algorithms like ZF, MMSE, ML, sphere decoder or K-best [8] are not amenable for cascading. This is because they do not need any initial solution vector for getting started. In addition, since some of them are able to provide near optimal error performance, at reasonable complexity, there was no occasion to explore cascading of different algorithms. However, this is true only for smaller MIMO systems and hence these conventional algorithms are not candidates for 5G networks.

IV. Simulation Results

For simulation purpose we use an open loop system (without dotted line in Fig. 1) where ELR based techniques [6] are used as algorithm A, sparsity boosted iterative linear (SBIL) [7] detector (an SER technique) for algorithm B and 1-LAS (likelihood ascent search) or RTS (reactive Tabu search) [3], [4] as NS algorithms. The BER performance for a 32×32 MIMO system with 16-QAM modulation is shown in Fig. 2a and Fig. 2b for four different combinations namely CD-1, CD-2, CD-3 and CD-4. These combinations are a cascade of (i) ELR-MMSE, SBIL and 1-LAS (CD-1) (ii) ELR-SIC, SBIL and 1-LAS (CD-2) (iii) ELR-MMSE, SBIL and RTS (CD-3) and (iv) ELR-SIC, SBIL and RTS (CD-4). From the figures it is clear that the complementary approach is able to significantly improve the error performance in the region $E_b/N_0 > 15$ dB. For example, at a BER of 2×10^{-3} there is a gain of more than 4 dB for CD-1 algorithm compared to existing standalone SBIL algorithm or standalone 1-LAS algorithm. The gains are even more for CD-2 algorithm (see Fig. 2a). This trend is maintained for CD-3 and CD-4 algorithms as can be observed from Fig. 2b.

Since all the algorithms considered have low complexity, the order of complexity of the proposed complementary scheme remains low.

V. Work in Progress

Apart from theoretically analysing the algorithms which are likely to maximize the benefits of complementarity, there are several other potential structures which need to be investigated. First and foremost will be to use NS algorithms for algorithm B and SER algorithms for algorithm C. This is because in the systems studied till now the initial vector for the NS algorithm was better than the initial vector for SER algorithms. It will be interesting to see the improvement in performance when the initial vector for the SER algorithm is better than the initial vector for the NS algorithm. Further, the error performance can be further enhanced if a feedback loop is introduced (shown in Fig. 1 by a dotted line). Lastly, the complexities of all the combinations considered here can be reduced if the erroneous location is used to generate a reduced neighborhood search as done in [9].

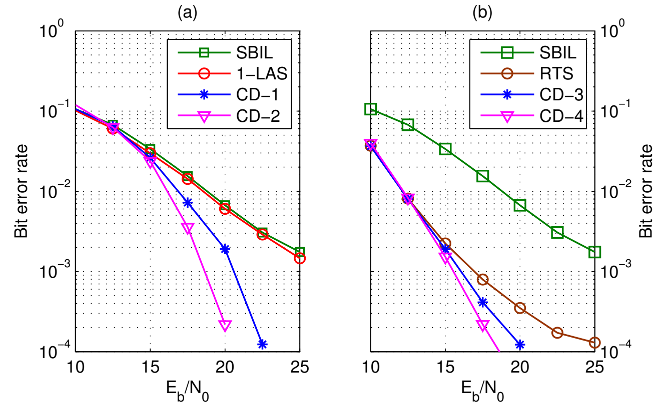

Fig. 2. Comparison for bit error performance of a 32×32 MIMO system for 16-QAM modulation.

VI. Conclusion

Large MIMO systems are promising candidates for realizing future 5G wireless networks. There is a need for improving the error performance of existing low complexity detection algorithms for their usage in large/massive MIMO systems. We conjecture that a right cascading of such algorithms has the potential to significantly improve the error performance while maintaining the same order of complexity.

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