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ADMM-BASED INFINITY-NORM DETECTION FOR MASSIVE MIMO: ALGORITHM AND VLSI ARCHITECTURE

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ABSTRACT

In order to improve the performance of large-scale MU MIMO wireless networks, we offer a new data detection technique and associated VLSI architecture. Our technique, dubbed ADMIN, is a limited equaliser that makes use of the infinity norm and relies on the alternating direction method of multipliers (ADMM). When the ratio of base-station (BS) antennas to user antennas is low, ADMIN, an iterative method, significantly outperforms linear detectors. When the ratio of BS to user antennas is big, ADMIN's first iteration of computing the linear minimal in 16- and 32-user systems, we design time-shared and iterative VLSI architectures. Our 28 nm complementary metal-oxide semiconductor (CMOS) ASIC designs for 16-64 antenna base stations with up to 64 quadrature amplitude modulation (QAM) are shown.

Keywords: CMOS, QAM, VLSI, ADMIN, BS, MMSE, TASER.

I INTRODUCTION

In order to manage orders of magnitude more data traffic, 5G wireless communication systems rely heavily on large (or enormous) multiuser (MU) multiple-input multiple-output(MIMO). In enormous MU-MIMO, the base station (BS) is outfitted with many antenna components so that it can support many user terminals operating in the same frequency range [1, 2]. The increased computational complexity of huge MU-MIMO systems over more traditional small-scale MIMO wireless systems is the price to be paid for their improved spectral efficiency. Several algorithms and VLSI designs have been presented lately [3]-[6] to allow high-speed communication in the uplink (users talk to the BS). These solutions all approximate the linear minimal mean-square error (MMSE) equaliser. In systems where the number of users is about equal to the number of BS antennas, these algorithms deliver high throughput but at the cost of performance compared to accurate inversion-based MMSE equalisers. The TASER data detector, presented lately by Casta neda et al., is based on approximate semidefinite relaxation and achieves near maximum-likelihood performance in such "symmetric" systems. However, TASER can only use BPSK or QPSK modulation.

The increasing acceptance of wireless networks has prompted innovative research. There are a number of factors at play here, including the ever-increasing demand for connectivity, the development of integrated circuit technology, and the successful deployment of standards that have vastly increased the availability of wireless connectivity, which in turn has stoked even more demand for brand-new products and services and the fundamental discoveries that make them possible. Despite significant progress, many unanswered questions remain in this field. In this thesis, I set out to close a number of gaps in the study of widely used wireless transceivers.

Fading and interference are two phenomena in wireless communication that provide special difficulties. Interactions between different transmitted signals in the same medium are described by the former, while variations in channel strength owing to small-scale and large-scale e®ects of multipath fading are described by the latter. Although interference often occurs between users, it may also arise inside a single user environment due to self-interference between the user's own signal components. Multi-antenna transmitter emissions (interference in space) and inter-symbol interference (ISI), or interference throughout time, are both types of self-interference. In this dissertation, I compare and contrast a number of transceivers that take on the problem of fading and interference in wireless networks. All but a few of the transceivers covered in this dissertation use linear circuitry and transmit and receive data over MIMO channels.

Several measures, including as the average likelihood of error and the outage probability, have been extensively accepted to characterise the performance of wireless networks. The concept of diversity [1, 2], defined as the slope of error probability as a function of SNR on the log-log scale, helps characterise these values in the fading channel. In non-fading channels, the error probability drops exponentially as the signal-to-noise ratio (SNR) increases, whereas in fading channels, the error probability is proportional to the signal-to-noise ratio multiplied by the channel diversity (d).

When signal-to-noise ratio (SNR) is high, channel throughput grows in line with log SNR. It has been shown that the channel dependability, measured by diversity, is inversely proportional to the throughput. The foundational study by Zheng and Tse [2] defined this tradeo® for the MIMO channel under maximum likelihood decoding, which led to the widespread use of the Diversity-Multiplexing Tradeo® (DMT) as a quality indicator for a broad range of wireless systems and methods.

1.2 Reasoning and Aims

This dissertation's major goal is to investigate the limits of MIMO system performance while using linear receivers and/or pre coders. A few DMT findings are also achieved, but the focus here is on the xed-rate domain, where the spectral efficiency R is insensitive to signal-to-noise ratio.

However, the DMT's inability to differentiate between different spectral sciences means that it fails to capture the variety present in the xed-rate regime, while being a robust framework. That are equivalent in terms of their multiplexing gain r. Different spectral efficiencies R give rise to different diversities [1, 2] in a number of real-world systems, even if they all correspond to the same multiplexing gain. In Chapter 2, we become more specific about the di®erence between calculating diversity in the xed rate regime and in the DMT.Due to the fact that some terms and mathematical expressions in DMT analysis are asymptotically irrelevant and may be discarded, fixed rate analysis of diversity necessitates different tools in comparison with DMT analysis.

II RELATED STUDY

Such approximate inversion-based linear methods work well under the assumption that the ratio between the number of antennas in the BS and the number of users is large. These algorithms provide high throughput but entail a significant performance loss compared to exact inversion-based MMSE data detectors, especially in systems with a comparable number of BS antennas and users. The performance of approximate inversion-based detectors are also very unstable, and their error-rate performance fluctuates greatly depending on the system and channel models, the number of users or BS antennas, coding scheme, algorithm structure, and the number of iterations. The performance can get worse to the point that such algorithms fail to successfully detect the transmitted data. The instability of approximate inversion-based algorithms can jeopardize the BS product development for network vendors who must support a variety of scenarios and configurations as customer requirement [15]. In practical MU detection scenarios below 6 GHz, the deployment of a large number of radio frequency (RF) chains may not be feasible due to the size, weight, and cost of the BS. The convergence rates of approximate-inversion-based data detectors will significantly deteriorate in such scenarios. A study in [16] suggested that exact matrix inversion-based detectors are viable alternatives from both complexity and latency perspective. A few implementations of exact-inversion-based data detection have been proposed in [17] and [18]. According to Björnson et al., there is a common misconception that massive MIMO refers to systems with at least an order of magnitude more base station antennas than terminals [19]. In fact, there is no strict requirement on the relation between the numbers of users and antennas in massive MIMO since the ratio depends on the system performance metric, propagation environment, and coherence time block length. In addition, network providers would be able to serve as many users as possible for the given number of BS antennas. Popular massive MIMO products, such as Nokia AirScale, Ericsson Air 6468, and Huawei AAU, are equipped with 64 antennas and can support up to 16 layers [20]. Therefore, massive MIMO systems with a small ratio between the number of BS antennas and users are of practical importance—however, only a few articles have studied data detection in such scenarios.

III PROPOSED SYSTEM

We propose a novel data detection algorithm based on the alternating direction method of multipliers (ADMM). Our algorithm is referred to as ADMM-based infinity-norm (ADMIN) and performs box-relaxation-based equalization, which outperforms linear detectors by a large

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margin in systems with small ratios between the number of BS antennas and users (two or less). ADMIN is iterative by nature and performs linear MMSE equalization in the first iteration. Therefore, for systems where the numbers of BS antennas are an order of magnitude larger than that of the users, it is sufficient to perform a single ADMIN iteration. We present an LDL-decomposition-based soft-output version of the algorithm and extensive simulation results to compare the error-rate performance of ADMIN with existing state-of-the-art data detectors. In addition, we design two iterative and time-shared VLSI architectures for ADMIN. Our architectures support 16 and 32 users for 16 and 32 BS antennas, respectively. We propose implementation results in 28-nm CMOS technology and on a Xilinx Virtex-7 field-programmable gate array (FPGA), and we compare our data detectors to existing ones in the literature.

DPC-Based Stochastic Multiplier

Schematic representation of DPC-based stochastic multiplier hardware. In order to better comprehend the structure, we have highlighted the logic gates and their respective functions. The multiplications in (22) and (24) are implemented by AND gates due to the Boolean nature of the signals AL, BL, CL, and DL. After computing "AL(t) • CL (t) • 2k," we remove it from "AL(t) • CL (t) • 2k."

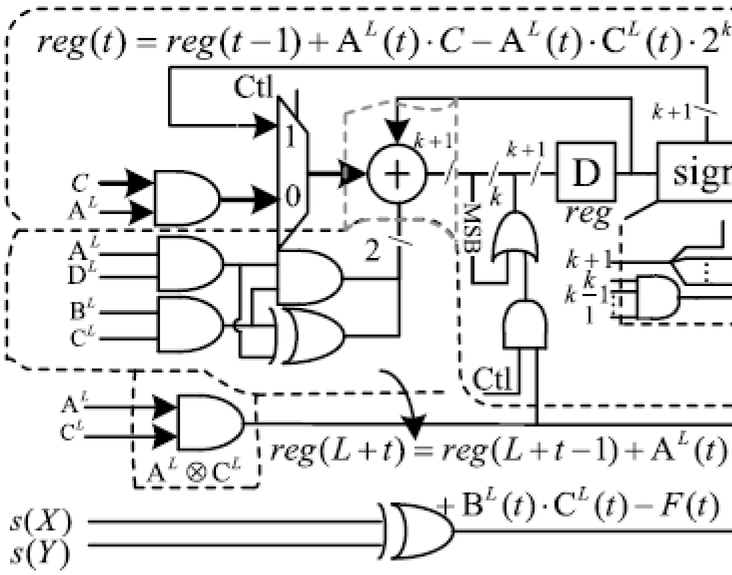

Fig. 2. High-accuracy stochastic multiplier.

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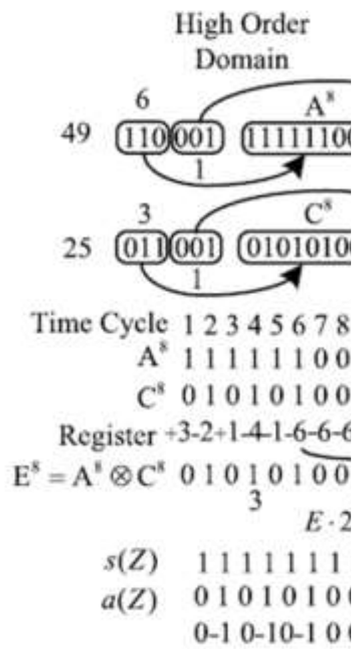
Case Study



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B. DPC-Based Stochastic Divider

In Fig. 3, we see the hardware implementation plan of the suggested SD. The B.C., or back converter, is a device that inverts

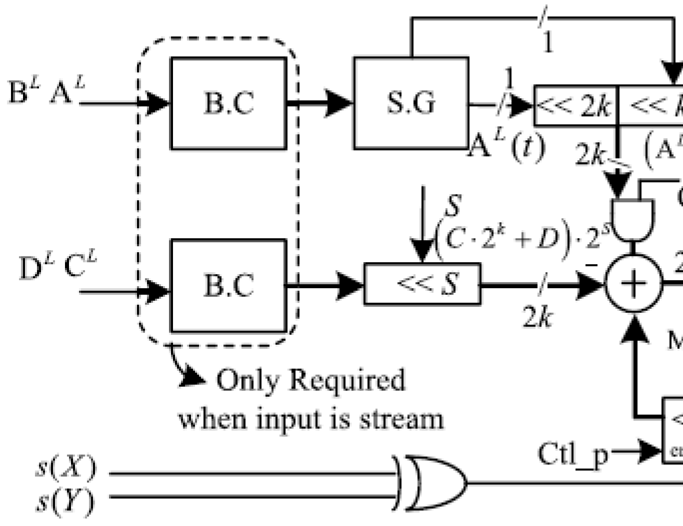

Fig. 3. High-accuracy SD.

When the input signal is already a TCS signal, the step of converting the stochastic stream to the FP signal is unnecessary. Left shifting AL(t) to 22k bits and BL(t) to 2k bits in a stream generator (S.G.) yields (AL(t) • 2k + BL(t))•2k. The register is modified by adding (38) in the first L = 2k cycles. The register's state is selected by a multiplexer based on EL (t). Using (37), we may produce the EL (t) output signal by inverting the MSB of the adder's output and then performing the comparison. The left shifting module at the register output is activated from cycle 2k+1 to the next cycle (41). To clarify, "Ctl_p" is a pulse signal having the form Ctl_p(t) = _1, t = 2k + 1, and 0 otherwise.

Next, we invert the most significant bit (MSB) ofadder output to get FL (t). To get the signedbit of Z's output, an XOR gate is used. In addition to its great accuracy, the suggested divider's logic design is straightforward.

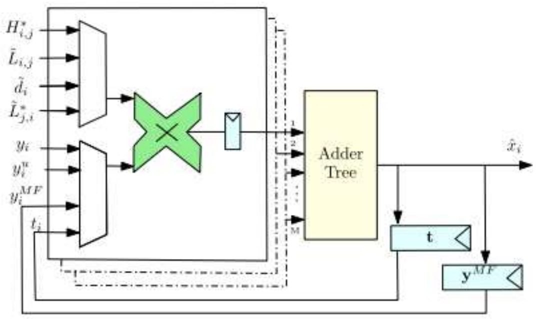

Fig.1. VM unit: Computes vector–vector multiplication.

The 32-user and 64-antenna architecture compute five iterations with a throughput of 88 Mb/s. An FPGA device can be reconfigured on-field by programming with different bitstreams. Therefore, an FPGA device configured for 32 antennas can be updated on-field with a new bitstream for 64 antennas. Thus, there is no crucial need for a dual mode architecture in FPGA that supports both 32 and 64 antennas. In Table IV, the resource utilization of the ADMIN variants on a Virtex-7 FPGA is presented. Even though the number of elements in L memory is roughly half of H memory, it can be seen from Table IV that L memory uses nearly the same or more LUTs. This is due to the control logic used for accessing both row and columns of the triangular register bank dedicated for L. The 16-user configuration uses 16 complex multipliers that are mapped to the 64 real multipliers available in the DSP elements. Therefore, the LUT slice usage of the VM unit is relatively lower than other units. Similarly, the 32-user configurations use 128 DSP elements because it uses 32 complex multipliers. The other section contains control logics, counters, and so on. A comparison with different state-of-the-art data detectors is presented in Table V. The most popular configuration for the FPGA implementations use eight users and 128 BS antennas, and thus, our design is not really comparable. Our goal is to compare ADMIN with other designs where the ratio between BS antennas and the number of users is equal to or less than 4. For this reason, we compare our design with two variants of TASER [28] and two variants of CD detectors [11], [30].

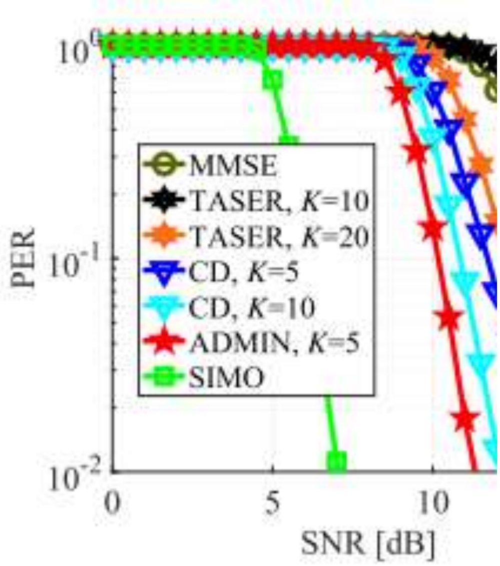

Fig.2. Sixteen BS antennas, 16 users, and QPSK.

All implementations in Table V used Xilinx Virtex-7 XC7VX690T FPGA, which gives us a fair comparison between the implementations. In [28], the TASER FPGA implementation results are provided for different BPSK and QPSK users per time slot. We take 64-users BPSK or 32-user QPSK TASERs to compare with our detectors. The resource utilization in TASER increases quadratically with the size of the systolic array. Therefore, while the number of LUTs in eight-user BPSK TASER is only 4790, the number of LUTs of 64-user BPSK TASER is 149 942. Thus, our design provides a significantly higher throughput/slices for all the configurations. The modulation scheme plays a crucial role in the lower throughput of TASER as it can support only BPSK and QPSK.

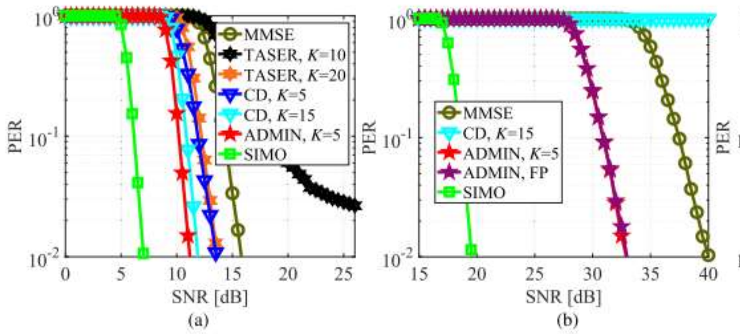

Fig.3. . Packet error rate (PER) for a massive MU-MIMO-OFDM system with rate-3/4 code and WINNER channels for 32 users

CONCLUSION

We have proposed ADMIN, a novel data-detection algorithm, and a corresponding VLSI architecture. The algorithm outperforms linear MMSE equalization in terms of PER by a large margin when the ratio of numbers between BS antennas and users is rather small (two or less). Our ADMIN architecture also provides promising results for 16-user and 32-user MIMO detectors in terms of area and energy efficiency. Thus, ADMIN enables a realistic large-scale MU-MIMO detector implementation for the fifth generation (5G) communication systems.

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