A LATTICE DIMINISHMENT BOLSTERED MIMO CHANNEL EQUALIZER

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Abstract— with the advancement in the wireless technology, the era of science in the world has changed radically. Wherever we see there is a use of wireless technology deployed to ease the work of mankind. The advancement in the 5th generation mobile wireless technology inspired us to do a research in the field of lattice diminishment.

The main agenda of our project entitled "lattice diminishment bolstered MIMO channel equalizer" is to reduce the lattice without compromising performance.

Over the past years, equalization of MIMO channels has gained much attention. Recently, the use of lattice diminishment methods for equalization for transmission over channels in the MIMO systems has been proposed in order to achieve good performance of the equalization scheme. Therefore, methods based on lattice based diminishment became a special interest for many researchers. To this end, several diminishment criteria and algorithms known from lattice theory has been applied. The architecture performs preprocessing steps at channel rate. Preprocessing is based on seysen's algorithm for lattice diminishment. We present algorithmic improvement of the lattice diminishment preprocess in terms of the area & throughput by implementing with minor impact on the error-rate. It turns out the stysen's algorithm & LLL diminishment perform differently with respect to these post-equalization SNRS, which explains their different error-rate behavior. Lattice diminishment bolstered detection has been shown to considerably increase the performance of linear MIMO detection systems. In this paper, we show that the conventional lattice diminishment is inherently in compatible with the use of different modulation formats across transmit antennas or more. Generally, the use of transmit power scaling. The second enhancement exploits temporal channel correlation to yield lattice diminishment based detectors exhibiting considerably reduced complexity. We examine the complexity & performance and review lattice diminishment. For typical mobiles environments, for example, we demonstrate a complexity diminishment approaching 33% on a 4*4 system, without compromising performance.

Index Terms— channel, diminishment, equalizer, lattice, MIMO, preprocessing, LLL, seysen's algorithm, SNRS.

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1. INTRODUCTION

In the past ten years the application of multiple antennas at the transmitter and the receiver has gained considerable interest in the research community. Employing multiple antennas at both the transmitter and the receiver linearly boosts, the channel capacity by min (nT, nR), where nT and nR are the number of transmit and receive antennas. Multiple-input multiple-output (MIMO) technology enables high spectral efficiency by using multiple antennas at both sides of the wireless link and by transmitting multiple data streams concurrently in the same frequency band. The joint reception of signals transmitted in parallel—either considering multi-antenna systems or multi-user scenarios—will become even more important over the next years. When designing transmission systems for such *multiple-input/multiple-output (MIMO) channels*, the interference among the individual signals has to be dealt with by means of equalization. The need for higher data rates in mobile communication applications spurred the development of multiple-input multiple-output (MIMO) technology, where multiple data streams are concurrently transmitted within the same frequency band. MIMO is often combined with orthogonal frequency division multiplexing (OFDM). OFDM transforms a frequency selective channel into a set of parallel frequency-flat channels and thereby simplifies the data detection. Many modern wireless communication standards (e.g., IEEE 802.11n/ac, 3GPP Long-Term Evolution, and other emerging 4G/5G systems) adopt the combination of MIMO and OFDM. For data detection in MIMO-OFDM communication systems many algorithms have been proposed. Linear detectors solve a linear system of equations to compute an estimate of the transmitted symbol. While these detectors have a low computational complexity, they suffer significantly in terms of bit error rate (BER) performance with ill-conditioned channels [1], [2]. Maximum likelihood (ML) detectors provide the best achievable BER performance for hard-output detectors and a posteriori probability (APP) detectors provide the best achievable BER performance for soft-output detectors. Furthermore, both detector types, ML and APP, provide full diversity (asymptotic slope of the error probability as a function of the signal-to-noise ratio (SNR)). Unfortunately, the computational complexity of ML and APP detectors for data transmission with large symbol constellation orders or large numbers of data streams is often costly in terms of area and power consumption, even when considering corresponding reduced complexity algorithms and implementations [3]–[7]. Furthermore, the computational complexity diminishment in [5]–[7] results also in a BER performance loss compared to a APP detector. In recent years, lattice reduction-aided linear detection (LRALD) [8], [9] has received more and more attention. LRALD seeks a compromise between complexity and BER performance. Similar to ML detectors, LRALD achieves full diversity [10], albeit with a small performance loss compared to the BER of ML detectors [11], [12]. In addition to the conventional LD scheme only a lattice diminishment (LD) step is required. This LD step finds a "more orthogonal" basis for the finite lattice generated by a MIMO wireless channel. As a consequence, the decision regions of linear detectors in the reduced basis are closer to the decision regions used by ML detectors [9]. Several LD algorithms are proposed in the literature [13]–[15]. For two-dimensional lattices (i.e., 2 2 communication systems), the Gaussian algorithm for lattice diminishment results in the best achievable diminishment [13]. For lattice dimensions larger than 2, various LD criteria and algorithms exist. Unfortunately, many of these LD algorithms exhibit a high computational complexity, which render the efficient implementation in hardware challenging. Existing reported implementations have been based on a few algorithms. Brun's LD algorithm, which was realized in [15], exhibits very low computational complexity. The BER performance can be further improved implementing LRALD using the Lenstra-Lenstra-Lovász (LLL) LR algorithm. Several application specific integrated circuit (ASIC) and field programmable gate array (FPGA) implementations reported in the literature are based on the LLL algorithm [16]–[19]. Another well-suited LD algorithm is Seysen's algorithm (SA). SA for LRALD was suggested in [20] and compared to LRALD with the LLL algorithm in [12]. A low-throughput processor-based implementation for software-defined radios is described in [21]. Despite the lower number of iterations [20] and the better error-rate for linear (i.e., for zero-forcing (ZF) and minimum mean square error (MMSE)) detection of SA compared to LLL [12], [20], no implementation of SA-based LRALD meeting the stringent throughput requirements of modern wireless communication standards has been presented so far. Moreover, all previously reported ASIC implementations of LR-aided MIMO detectors do not comprise all the necessary steps to perform preprocessing and data detection. Therefore, these results do not provide full insight into the true silicon complexity of LRALD detectors.

2. MOTIVATION FOR LATTICE DIMINISHMENT

One of the main factors limiting the detection performance of MIMO receivers is the correlation between the basis vectors which form the channel matrix. On one hand, the Maximum-Likelihood (ML) detector makes decisions based on optimal closest-point search [11]. Therefore, its results are independent of the basis used and consequently the ML detector is not strongly affected by the correlation of the basis chosen to represent the channel 1. On the other hand, non-optimal detectors (both linear and non-linear) depend heavily on the choice of the basis and as a result these detectors cannot achieve full diversity unless the basis vectors are perfectly orthogonal (i.e. they have zero correlation) which is very rarely the case in a typical channel, due to multi-path effects and antenna design constraints [12,13]. Moreover, the higher the correlation between the basis vectors, the lower the diversity achieved by non-optimal detectors. As a result, they perform very poorly in the presence of ill-conditioned channels (channels with highly correlate basis vectors). The conclusion is that in order to close the gap to ML performance and achieve higher diversity, the channel matrix must be transformed so that it is represented by an orthogonal (or nearly-orthogonal) basis, thereby minimizing the correlation and maximizing the achievable diversity. Recently, the application of Lattice diminishment (LD) techniques to MIMO communication systems was proposed with the aim of closing the gap to the ML performance limit [14]. The term lattice diminishment refers to the linear transformation of the basis vectors representing the channel matrix so that they become orthogonal or nearly-orthogonal without changing the actual constellation points. This in effect decreases the correlation between the basis vectors and results in a better-conditioned channel matrix. The LD technique used in [14] is the Gaussian diminishment algorithm, which is the simplest form of lattice diminishment and is only applicable to the 2x2 MIMO case. Using lattice diminishment significantly improved the performance of linear detectors and the diversity achieved was shown to match that of ML. This was a major milestone since no previous linear MIMO detector could achieve ML diversity. This compelling improvement in the performance of linear detectors as a result of using lattice diminishment initiated a large number of research efforts directed at expanding on the work of [14]. This included: (a) expanding the application of lattice diminishment to arbitrarily higher dimensions (4 × 4, 6 × 6, 8 × 8, . . .) by using LD algorithms other than Gaussian diminishment, and (b) extending these new LD techniques to apply to non-linear detectors. However, for dimensions higher than 2 × 2, the lattice diminishment technique becomes exponentially more complex. As a result, the associated LD algorithms exhibit high complexity as well as a non-deterministic runtime, rendering them unsuitable for a practical hardware implementation.

3. OBJECTIVES

LD techniques have the potential for not only significantly improving the performance of MIMO detectors, but also enabling the diminishment of the detection complexity while maintaining low BER performance. This diminishment in complexity of LD-aided MIMO detectors, which is made possible by the improved condition of the channel matrix, allows for higher throughput as well as more efficient and cost-effective VLSI implementations, thereby enabling MIMO systems to match the aggressive specifications of 4G wireless standards such as data rates of up to 1Gbps, large constellation orders (64-QAM and 256-QAM) and large antenna configurations (4 × 4 and 8 × 8). In order to realize the true potential of lattice diminishment, there is a need to develop a near-optimal low-complexity LD algorithm suitable for high-throughput VLSI implementation. This has yet to be achieved in a practical hardware system. To date, there have only been a few hardware implementations of LD algorithms, namely [15–19]. Each of these implementations attempts to optimize the LD algorithm for hardware implementation. However, because of the inherent complexity and iterative nature of the existing LD algorithms, these implementations suffer from high computational complexity, low throughput and non-deterministic runtime, and therefore cannot be used in a real time MIMO receiver. In addition, most of these LD designs have been implemented on Field-Programmable Gate Array (FPGA) platforms, with none realized and silicon-proven in a practical high performance Application-Specific Integrated

Circuit (ASIC) chip implementation. The objective of this thesis is to design and implement the first LD ASIC core with silicon-verified results. The designed LD core is required to meet the high data rates envisioned for 5G standards such as WiMAX and LTE-Advanced. This objective can be broken down into several steps as follows:

1. Development of an optimized LD algorithm: This entails examining the existing state-of-the-art LD algorithms, selecting the most efficient algorithm in the context of MIMO detection and then optimizing the selected algorithm for an efficient VLSI implementation. Optimization goals are to reduce complexity, achieve deterministic runtime and reduce the number of required iterations; all while maintaining high quality lattice diminishment.
2. Efficient Hardware Design: Once an optimized algorithm is reached, an efficient architecture must be designed for it. The VLSI design is required to have high-throughput necessary for 5G data rates as well as low power required for implementation in 5G mobile systems with limited power resources. In addition, bit-true simulations must ensure that the lattice diminishment quality remains high and is only marginally affected by the fixed-point implementation.
3. Silicon-proven implementation: Following hardware simulation and verification, the design is implemented on an ASIC platform. The fabricated chip should be tested and shown to meet 5G throughput specifications as well as low power requirements.

4. EXISTING SYSTEM

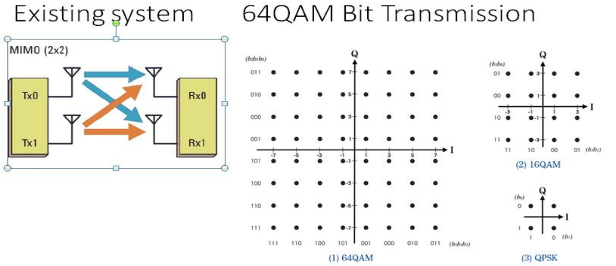


Fig.1 existing system

5. PROPOSED SYSTEM

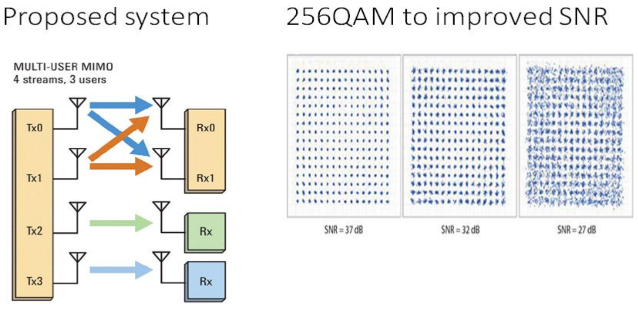


Fig.2 proposed system

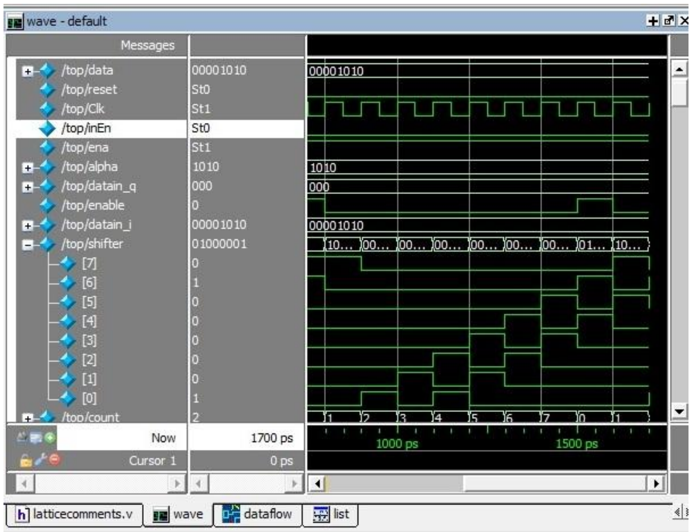
6. LATTICE DIMINISHMENT BOLSTERED EQUALIZER

The idea of *lattice- diminishment -bolstered equalization* for MIMO channels is to combine methods known from lattice theory, in particular *lattice diminishment*, i.e., the generation of a more suited representation of a lattice, with traditional low-complexity detectors, in particular simple linear equalization. Having performed the complex pre-processing step for finding the reduced basis (e.g., using the LLL algorithm [6]), detection complexity is reduced dramatically at the cost of moderate performance degradation. Starting point is an equivalent real-valued MIMO channel model $y = Ha + n$ obtained from the initial complex one by separating real and imaginary parts [7]. The matrix H comprises the fading coefficient between each pair of transmit and receive antenna, x is the column vector of real channel input symbols ak, drawn from a regular grid (translate of the integer lattice Z), n the vector of additive white Gaussian noise samples nk, and y is the vector of received signals. Since $ak \in$ Z, at the receiver side the lattice HZK, where K denotes the dimension of the input vector, is present. The same lattice may be described by basis vectors which are pair wise close to orthogonal. Such a basis can be found by lattice (basis) diminishment [6] which factors H as $H = H$red$R$, (1) where R is a matrix with integer entries that has unit determinant, i.e.,R–1 also contains only integer entries. Now, instead of linear equalization of H, only the factor Hred is linearly equalized. Since RZK = ZK the (noise-free) decision symbols are drawn from the integer grid, and individual threshold decision of each component to the integer grid can be performed. Thereby, the noise enhancement due to H–1 red is lower than that of H–1 and a gain in performance is achieved. Finally, to recover data, via R–1 estimates ˆak of the initial data symbols are generated.

7. MIMO-OFDM System

Orthogonal Frequency Division Multiplexing (OFDM) is a very popular wireless communication modulation scheme, which has been developed to efficiently handle communication over multiple transmitter and receiver antennas [20]. OFDM is characterized by the transmission of multiple parallel data streams, referred to as subcarriers, such that the Sub carriers are orthogonal to each other in the frequency domain. Each subcarrier is modulated through traditional modulation schemes such as Quadrature Amplitude Modulation (QAM) or Phase Shift Keying (PSK). The orthogonality of the subcarriers makes OFDM very robust against Inter Symbol Interference (ISI), and can be efficiently implemented through an Inverse Fast Fourier Transform (IFFT) operation on the transmitter side and a Fast Fourier Transform (FFT) operation on the receiver side. A simplified architecture of a MIMO-OFDM system is shown in Fig. 2.1. Starting with the transmitter on the left side, a binary source produces a binary sequence which is demuxed into NT signals and then modulated to points on the constellation through the mapper. The modulated signals are passed through an IFFT operation, converted to their analog counterparts and transmitted via NT antennas. The transmitted signals pass through a channel modeled by the matrix H, and then they are received by NR antennas. After an analog to digital conversion and an FFT operation, the received signals are fed to two paths: one is the main detection path that includes the MIMO detector, while the other path is used for channel estimation and preprocessing. The estimated and preprocessed channel is forwarded to the MIMO Detector, which produces the estimated symbols. These symbols are then multiplexed, demapped and converted into the estimated binary sequence.

8. SIMULATION RESULTS:



Messages	
/top/data	00001010
/top/reset	St0
/top/Clk	St1
/top/inEn	St0
/top/ena	St1
/top/alpha	1010
/top/datain_q	000
/top/enable	0
/top/datain_i	00001010
/top/shifter	01000001
[7]	0
[6]	1
[5]	0
[4]	0
[3]	0
[2]	0
[1]	0
[0]	1
/top/count	2
Now	1700 ps
Cursor 1	0 ps

Fig: simulation result in modelsim

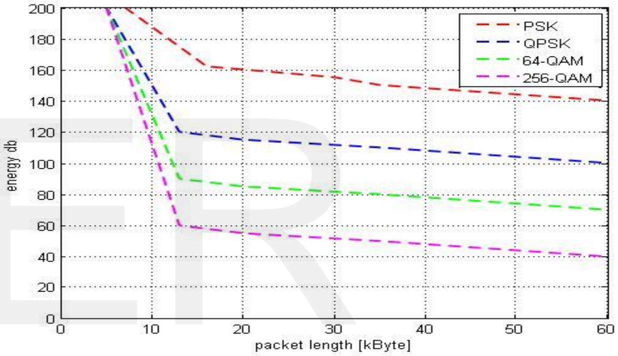


Fig: simulation result in matlab

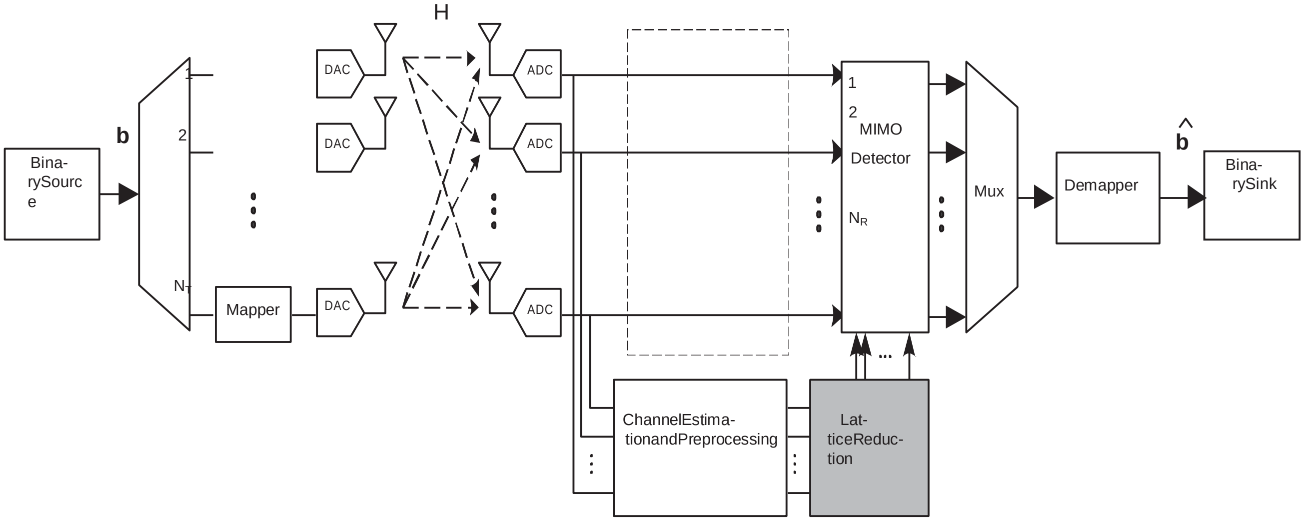


Figure 4: MIMO-OFDM System Model

9. CONCLUSION

In this paper we propose a low-power, low-complexity hard output MIMO detector that approaches or exceeds the performance of many other hard-output and some soft-output or even iterative receivers. The key element of the design is to use a relatively complex one-time pre-processing of the channel matrices Using Seysen's algorithm (SA) for lattice diminishment followed by a low-complexity linear receiver for energy-efficiency. To reduce the pre-processing overhead from the algorithm side, we introduce an iteration limit and we constrain the dynamic range of the update coefficients in SA. On the architectural side, a pipelined architecture provides the high throughput and low latency required for MIMO-OFDM systems with stringent pre-processing-latency constraints and a block floating-point scheme reduces the bit width requirements compared to a conventional fixed-point representation. On the detector side, we propose to flag unreliable receive symbols with elements that (after remapping) lie outside the valid constellation by using the uncturing mode of the subsequent channel decoder. This novel handling of such symbols results in a bit-error-rate improvement of up to 0.75 dB SNR compared to lattice diminishment aided linear detection which simply maps such outliers to the nearest constellation point.

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