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Research Article

VLSI Implementation of Low Complexity MIMO Detection Algorithms

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ABSTRACT

This paper presents VLSI implementation of low complexity multiple input multiple output (MIMO) detection algorithms which are Maximum Likelihood and Zero Forcing. Initially, the MIMO system structure, the mathematical model and two receiver detection algorithms are presented. Then we investigated the characteristics and performance of typical algorithms and concentrated on VLSI implementation of the system architecture and the two detection algorithms, which can give good performance. Finally, simulation results have been compared with each other in terms of complexity and error performance.

Keywords: VLSI; MIMO, Detection Algorithms, ZF, ML, FPGA, BER, Low Complexity

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ELECTRONICS RESEARCH ARTICLE

VLSI Implementation of Low Complexity MIMO Detection Algorithms

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ABSTRACT

This paper presents VLSI implementation of low complexity multiple input multiple output (MIMO) detection algorithms which are Maximum Likelihood and Zero Forcing. Initially, the MIMO system structure, the mathematical model and two receiver detection algorithms are presented. Then we investigated the characteristics and performance of typical algorithms and concentrated on VLSI implementation of the system architecture and the two detection algorithms, which can give good performance. Finally, simulation results have been compared with each other in terms of complexity and error performance.

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1. INTRODUCTION

Multiple Input Multiple Output (MIMO) is used to describe the multi-antenna wireless communication system, an abstract mathematical model can take advantage of a plurality of transmitter antennas are each independently a transmission signal, and a plurality of antennas at the receiver receive and recover the original message. In MIMO communication system without increasing the transmission bandwidth channel capacity increases exponentially [1]. MIMO technology is the future wireless communication systems to achieve high data rate transmission, to improve transmission quality, an important way to improve the system capacity.

Zero Forcing (ZF) and Maximum Likelihood (ML) detection algorithms are used to separate the spatially multiplexed data units at the receiver [2]. Implementing the design using FPGA is very fast with lower development costs and takes less amount of time. VLSI implementation of the detection algorithms in the MIMO system will turn out to be a key methodology in the future wireless communication system.

This paper is arranged as follows: Section II gives brief overview of system model. Section III presents the detection algorithms like Zero Forcing and Maximum likelihood detection algorithms. Section IV shows the results of Bit Error Rates and also hardware implementation results and section V is conclusion of the paper. This paper investigates the applicability of FPGA system for low complexity MIMO Detection algorithms in effective and economical way.

2. SYSTEM MODEL

Here a MIMO with N_t transmit antennas and N_r receive antennas is considered. A block diagram of system is shown in figure 1.

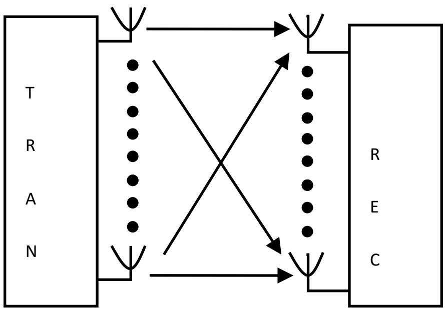

Figure1. Basic MIMO System Model

Received signal

$$Z_r = H_r X_r + n_r \quad (1)$$

Where r=1, 2, 3 ... R, R is the number of sub carriers and received signal vector $Z_r = [Z_{r1}, Z_{r2}, ... Z_{rN_r}]^T$, Transmit Signal vector $X_r = [X_{r1}, X_{r2}, ... X_{rN_t}]^T$, $n_r = [n_{r1}, n_{r2}, .. n_{rN_t}]^T$ is the additive noise vector and represents white guassian noise of variance σ^2 . H indicates the $N_r x N_t$ channel matrix. In order to identify the communicated data it would be best to use ML detector [3].

A couple of significant problems exist with planning channel estimators. First one is the preparation of pilot information, which is used as the reference signal handled by both transmitters and receivers. The second trouble is the strategy of an estimator by means of both low complexity as well as great channel tracking potential and also both of these issues are interconnected. MIMO Wireless communication systems require the low complexity and high precision detectors to achieve high data rates with low BER. The channel estimations are generally adopted in MIMO systems to achieve the trade-off between complexity and accuracy.

In the 2 × 2MIMO channel model, the number of pilot signals may be 2 When the pilot signal$p_1 p_2$= [1 0],

$$r_1 = H_{11} \times p_1 + H_{21} \times p_2 + n_1 \quad (p_1 = 0) \quad (2)$$

$$r_2 = H_{12} \times S_1 + H_{22} \times S_2 + n_2 \quad (p_1 = 0) \quad (3)$$

This does not consider the effect of noise. There are

$$H_{11} = r_1 / p_1, H_{21} = r_1 / p_2 \quad (4)$$

$$H_{12} = r_2 / p_1, H_{22} = r_2 / p_2 \quad (5)$$

When the pilot signal$p_1 p_2$= [0 1],

Therefore, using the guide structure, the receiving end can estimate the channel H is:

$$H = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix} \quad (6)$$

Pilot-based methods [4] are extensively used to approximate the channel properties and extract the received signal. The pilot signal allocated to a specific block, which is directed periodically in time-domain, this type of pilot procedure is particularly appropriate for slow-fading radio channels. Since the training block comprises all pilots, channel interpolation in frequency domain is not required. So, this kind of pilot scheme is reasonably unresponsive to frequency selectivity. Comb-type pilot system is provides better resistance to fast-fading channels. Since only some sub-carriers contain the pilot signal, the channel response of non-pilot sub-carriers will be estimated by interpolating neighboring pilot sub-channels. Thus the comb-type arrangement is sensitive to frequency selectivity when comparing to the block-type pilot arrangement system. In block-type pilot based channel estimation, OFDM channel estimation symbols are transmitted periodically, in which all sub-carriers are used as pilots [5]. If the channel is constant during the block, there will be no channel estimation error since the pilots are sent at all carriers. The estimation can be performed by using Zero Force, ML, LS, and MMSE.

Detection Algorithms

Maximum Likelihood Detection (MLD)

This is the theoretical optimum detection method can receive diversity gain full access. By the estimation theory, for Y = HX+Z, H estimation, maximum likelihood estimation method to construct a cost function p (H|Y, X) so that the cost function to obtain the maximum value of H is the final estimate

$$\hat{H} = \arg\max_{H} \{ p(H / Y, X \} \quad (7)$$

This paper is focused on the 4 × 4 MIMO system simulation, constellation map of QPSK, at the receiving end using the maximum likelihood detection algorithm is to investigate channel estimation algorithm performance, so when testing using the transmitted signal space uses exhausted search approach to maximum likelihood detection [6], in order to fully demonstrate channel estimation algorithm BER performance.

Zero Forcing Detection (ZF)

Zero forcing detection algorithm is a channel to the reception signal by the inverse matrix of the interference of other users it can be eliminated, but the noise is also multiplied by the inverse of the channel matrix, in general, the channel coefficient matrix is less than 1, then it the inverse is greater than 1, ie to the noise by a factor greater than 1, the noise must be amplified. The zero forcing detection multiplies the received symbol vector y by an equalization matrix G i.e.

$$\hat{x} = G_{ZF} y \quad (8)$$

Zero Forcing means that the mutual interference between the layers shall be perfectly suppressed [7].

This is derived from the Moore-Penrose Pseudo Inverse of H

$$G_{ZF} = (H^H H) \quad (9)$$

3. RESULTS AND DISCUSSION

Matlab Simulations

From Figure2 it can be seen that the detection of the ML, when the transmitting and receiving antennas are more, error rate is lower, so that the MIMO communication system can overcome the adverse multipath fading effects, to achieve the reliability of signal transmission, but also can increase the system capacity and hence improves the spectrum efficiency[8].

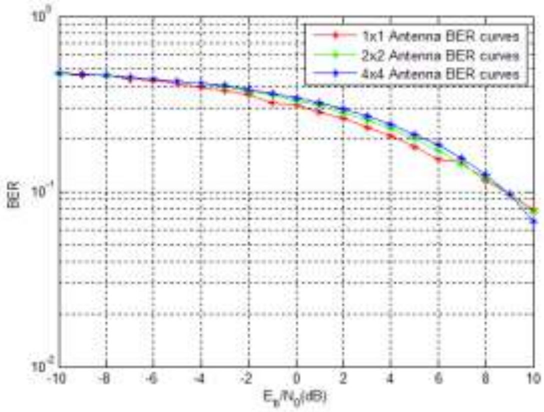

Figure2.Pilot estimated channel, ML Detection MIMO System 1x1, 2x2, 4x4 Antenna Performance

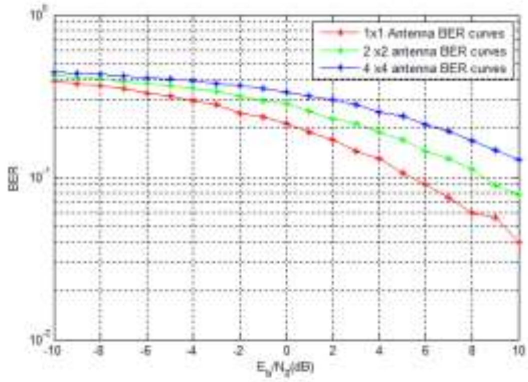

Figure3. Pilot sequence estimated channel, ZF Testing under, MIMO System 1x1, 2x2, 4x4 Antenna performance comparisons

From figure 3 and figure 4 it can be seen in ZF detection, when the transmitting and receiving antennas, the more the higher the bit error rate, is zero forcing detection algorithm to the reception signal by the inverse of the channel matrix, the other users of its the interference can be eliminated, but the noise is also multiplied by the inverse of the channel matrix, in general, the channel coefficient matrix is less than 1, then its inverse is greater than 1, that is a noise by a factor of greater than 1 , must be amplified noise. So the error rate will increase as the number of antennas increases.

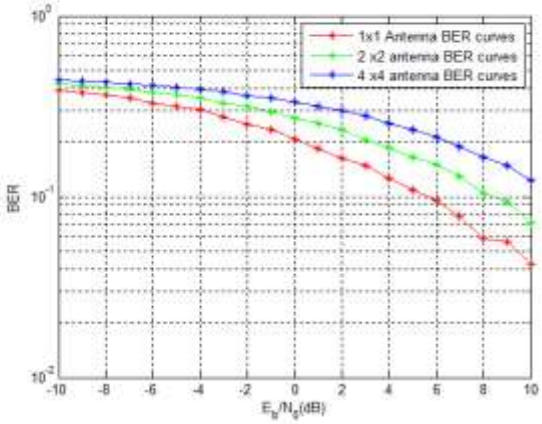

Figure4. Ideal channel, ZF detection 1x1, 2x2, 4x4 MIMO antenna system error rate

From the results which are shown in figure 5 and 6 it can be seen, the use of ML detection, the ideal channel and the estimated channel error rate overall trend is same, but the ideal channel bit error rate than the estimated channel bit error rate is low, indicating that based on the pilot channel estimation in MIMO communication system is feasible.

Using ZF detection, ideal channel and estimated channel error rate overall trend the same, but the ideal channel bit error rate than estimated channel bit error rate is high, it is generally not recommended for pilot-based channel estimation using ZF detection algorithm[9].

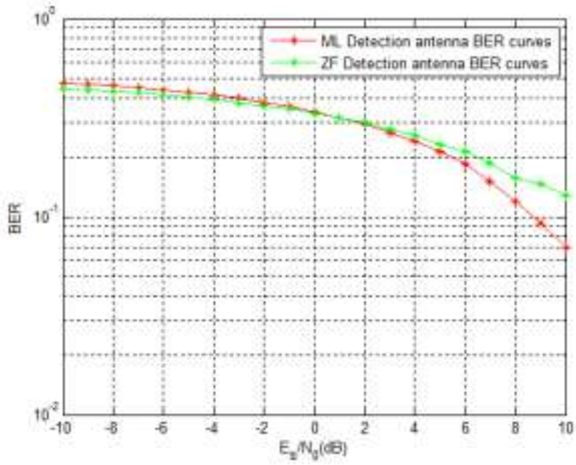

Figure5. Estimate the channel,MLD And ZFTesting under 4x4Antenna MIMOComparative analysis of the bit error rate curve

It can be seen from the results of figure 5 and figure 6, when using the ideal channel, MLD algorithm error rate than the ZF algorithm is small, and the same general trend, but at high SNR part MLD algorithm BER than the ZF algorithm is obviously much lower , indicating that global search algorithm MLD excellent performance.

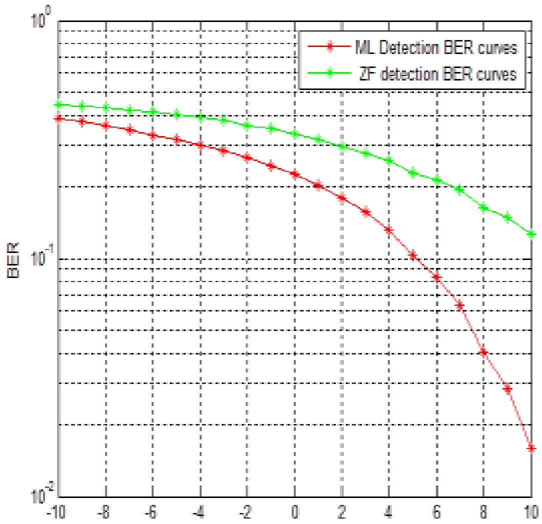

Figure6. Ideal channel, MIMO 4x4 antenna system MLD detection and ZF detection performance comparison

When using the estimated channel, MLD algorithm and the ZF algorithm BER less, where MLD algorithm is slightly lower SNR. From the computational point of view and run time, when the num = 256, loop = 1000, the use of a total of about MLD algorithm 1200s, the use ZF algorithm needs a total time of about 180s. MLD algorithm is much larger than the amount of computation ZF algorithm, the time is also longer than the ZF algorithm.

FPGA Implementation

The architecture was designed concentrated on great performance and low cost. The architecture was defined in Hardware Description Language and synthesized to Xilinx Virtex 4 FPGAs. The synthesis results demonstrate that the architecture is capable to accomplish processing at faster rates and attains the real-time requirements. The architecture is consuming fewer resources when compared to related works [10].

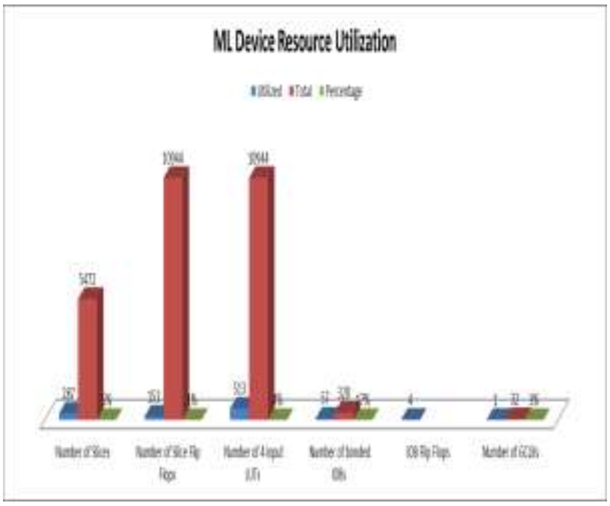

Figure7. ML device utilization summary for Virtex 4, 4vsx25ff668-12 Deivce

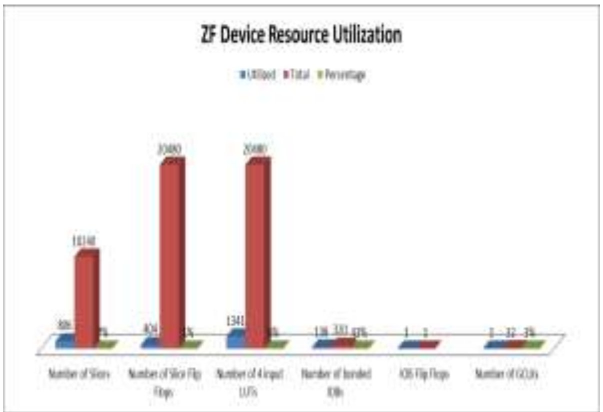

Figure8. ZF device utilization summary

4. CONCLUSION

Through this approach, we know that the multipath MIMO wireless channel with transmitter and receiver as a whole is optimized to achieve high communication capacity and spectrum utilization. This is a near-optimal joint airspace domain diversity and interference cancellation processing. This is started through the establishment of MIMO communication system, and based on pilot estimates the channel H, and then using the estimated channel respectively MLD and Zero-forcing signal detection, and finally the application of MATLAB on the system simulation, drawing, observation graphics, simulation results BER analysis. From the above process for the project, we further understand the performance of MIMO system outstanding advantages for the future laid the foundation for learning 4G communications.

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