Low Power Layered Space-Time Channel Detector Architecture for MIMO Systems

T. Takahashi[1], A.T. Erdogan[1,2], T. Arslan[1,2], and J. H. Han[2]

[1]Institute for System Level Integration, Livingston EH54 7EG, UK
[2]School of Engineering and Electronics, University of Edinburgh, Edinburgh EH9 3JL, UK
E-mail: Tetsuya.Takahashi@sli-institute.ac.uk, {ate, ta, j.han}@ee.ed.ac.uk

Abstract

This paper presents the low power implementation of a Maximum Likelihood (ML) based detector used in the receiver part of a Multiple Input and Multiple Output (MIMO) systems. Low power is mainly achieved through complexity reduction of the ML detector. In particular, Manhattan metric approach is proposed for removing the need for the use of multipliers in the architecture, leading to significant complexity reduction in the ML detector implementation with only 0.7 dB loss in the Bit Error Rate (BER) performance. Results are presented showing that our ML detector achieves 29% saving in area and 34.4% saving in power consumption compared to conventional implementations.

1. Introduction

Multiple-input multiple-output (MIMO) is the leading technology for high throughput transmission in a multipath fading environment. MIMO systems provide a nearly linear increase of capacity with the number of transmit antenna elements, affording significant increase over conventional systems, and this leads to the increase of the transmit capacity and the Quality of Service (QoS) [1].

Concurrent transmission with multiple antennas is the basic technique for MIMO systems where the transmission is performed with the diversity in space and time domain. This technology is called Layered Space-Time (LST) architecture and was proposed by Foschini [2]. There are several LST architectures proposed, and in particular Bell Labs Layered Architecture Space-Time (BLAST) is well known and researched.

Transmit techniques have been developed to achieve high throughput. However, the receiver is also one of the key elements of the system. Since MIMO system uses the multipath environment as the source for higher transmission, the receiver has to deal with multi stream interferences. Moreover noise or fading problems also need to be solved in practice.

The MIMO system can be represented as follows:

$$\mathbf{r} = \mathbf{Hs} - \mathbf{n} \qquad (1)$$

where $\mathbf{r} = [r_1, \ldots, r_R]^T$ is the vector of received symbols, $\mathbf{H}$ is the RxT channel matrix, $\mathbf{s} = [s_1, \ldots, s_T]^T$ is the vector of transmitted symbols, and $\mathbf{n}$ is additive white Guassian noise (AWGN).

Since each received channel is convoluted with each other, the receiver has to differentiate the multiple data [2]. This requirement leads to higher complexity of the system and hence higher power consumption. Hence, there are some algorithms to reduce the complexity such as sphere decoding [3] and QR decomposition [4]. However, this paper proposes a new approach for reducing the complexity of MIMO channel detector. In particular, this paper proposes the Manhattan metric approach for eliminating the use of multipliers, leading to significant complexity reduction in the channel detector implementation.

2. Maximum likelihood detector (MLD)

The basic architecture of a MIMO detector consists of two parts: estimation and detection. In the estimation part, the candidates of received signal are estimated based on the modulated symbols and the channel matrix. With the estimated candidates, the actual received signals are detected in the detection part. There are several algorithms used to decide which candidate is matched best with the received symbol.

MLD is chosen in this paper because of its optimal BER performance. The ML detection algorithm can be expressed with the equation below:

$$\hat{s} = \arg\min_{s \in \wedge} \left\| \mathbf{Hs} - \mathbf{r} \right\|^2 \quad (2)$$

Proceedings of the 2006 Emerging VLSI Technologies and Architectures (ISVLSI'06)
0-7695-2533-4/06 $20.00 © 2006 **IEEE**

where the best candidate, $\hat{\mathbf{s}}$, is selected which minimises the distance between the received symbol, **r,** and all the estimated candidates, **Hs**.

3. Complexity reduction

There are several reduction algorithms as mentioned before, and most of them are about the reduction of search steps. However, this paper presents a novel approach to reduce the number of multipliers. As mentioned above, ML algorithm searches the most probable one from all the candidates by calculating the distance between the received symbols and weighted candidates. Euclidean distance is traditionally used, which is the direct and exact distance, as shown in equation (3). However, this metric system requires the use of multipliers.

$$D = \sqrt{(Ax - Bx)^2 + (Ay - By)^2} \qquad (3)$$

$$D' = |Ax - Bx| + |Ay - By| \qquad (4)$$

In this paper, Manhattan metric approach is proposed to reduce the complexity of computing the distance between the received symbols and weighted candidates. This metric is based on the addition of the X component and the Y component, as expressed by equation (4). It is clear that Manhattan metric does not require any multiplications and this leads to significant reduction in computational complexity.

However, while Manhattan metric can reduce the complexity, it incurs some loss in BER performance. Fig. 1 illustrates the BER performance results obtained with MATLAB simulations. It is clearly shown that the BER performance of Manhattan metric system is about 0.7 dB lower than that of Euclidean metric system which represents 5% loss in BER. Nevertheless, this result is still much better than that of V-BLAST.

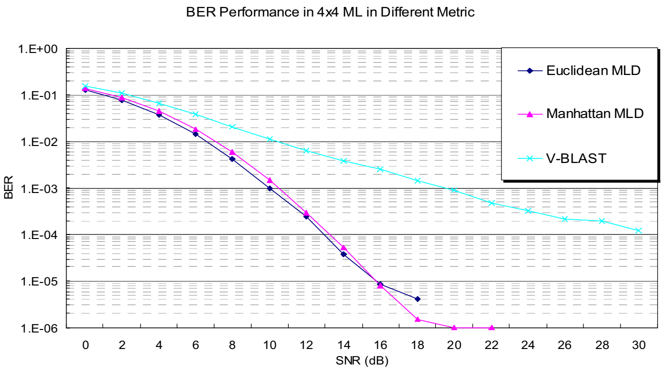

Figure 1. BER performance analysis

4. Simulations and results

In this paper, two architectures have been synthesised and compared: one based on Euclidean and one based on Manhattan metric calculations. Synthesis has been carried out with Synopsys Design Compiler using UMC 0.18um CMOS standard cell library and power estimation has been performed with Synopsys Power Compiler.

Table 1 shows the area and power comparisons of Euclidean and Manhattan based implementations for a clock frequency of 100 MHz. Clearly, Manhattan approach achieves 29% reduction in area and 34.4% in power consumption.

Table 1. Performance comparisons

	Euclidean	*Manhattan*	*Saving (%)*
Speed (MHz)	*100*	*100*	-
Area (um^2)	*1028181*	*730184*	*29*
Power (mW)	*145.62*	*95.51*	*34.4*

5. Conclusion

In this paper, a low power architecture for the implementation of an ML detector for MIMO systems has been presented. Manhattan metric approach has been proposed for reducing the complexity of the detector with only 0.7dB loss in BER performance. It has been shown that the proposed approach can reduce area and power consumption by 29% and 34.4% respectively. In addition, the architecture achieves higher throughput compared to an Euclidean based implementation.

6. References

[1] *Bells Laboratory, "BLAST High-Level Overview", http://www1.bell-labs.com/project/blast/high-level-overview.html.*

[2] *G. J. Foschini, "Layered Space-Time Architecture for Wireless Communication in a Fading Environment When Using Multiple Antennas", Bell Labs Technical Journal, Vol. 1, No. 2, Autumn 1996, pp 41-59.*

[3] *D. Garrentt, L. Davis, S. T .Brinnk, B. Hochwald, and G. Knagge, "Silicon Complexity for Maximum Likelihood MIMO Detection Using Spherical Decoding", IEEE J. of Solid-State Circuits, vol.39, no.9, Sep. 2004, pp.1544-1552.*

[4] *H. Kawai, K. Higuchi, N. Maeda, M. Sawahashi, T. Ito, Y, Kakura, A Ushirokawa, and H, Seki, "Likelihood Function of QRM-MLD Suitable for Soft-Decision Turbo Decoding and Its Performance for OFCDM MIMO Multiplexing in Multipath Fading Channel", IEICE Trans. comms, no.1 Jan. 2005, pp 47-57.*