VLSI Implentation of Viterbi Decoder in MIMO Systems

Glory Priscilla, P.Deepthi, K.V.Ramana Rao

Abstract*— *Space-time trellis code (STTC) has been widely applied to coded multiple-input multiple-output (MIMO) systems. The complexity of STTC decoding lies in the branch metric calculation in the Viterbi algorithm and increases significantly along with the number of antennas and the modulation order. Consequently, a low-complexity algorithm to mitigate the computational burden is proposed. The design is implemented Xilinx Spartan 3 Xc3s200E fpga and the total power consumed by the device is 0.041W.

Index Terms*—*Branch metrics, MIMO, space-time trellis code, Viterbi decoder.

I. INTRODUCTION

In recent years, multiple-input multiple-output (MIMO) transmission technology has been widely applied to various wireless communication systems. MIMO technology is divided into two categories, spatial multiplexing and diversity coding.In the spatial multiplexing technique, the data is split into multiple streams, which are transmitted and received by multiple antennas. Subsequently, the receiver detects the transmitted symbols from the signals received by the multiple receiving antennas. In addition, the diversity coding technique has a better capability of resisting the channel impairment. The most popular diversity coding technique is space-time coding (STC) which involves space diversity, modulation, and error correction. The STC can moderately improve the spectral efficiency and provide coding gains for error correction.

The space-time trellis code (STTC) was also proposed to improve both the diversity gain and coding gain for wireless communication systems. The STTC encoder generates redundant parity check codes which are transmitted with the original information data streams, and thereby coding gain is obtained. Therefore, the STTC technique possesses a more robust capability than the STBC technique for combating severe MIMO channel impairment.

Viterbi decoder chips have been published for convolutional codes (CC) and trellis-coded modulation (TCM) techniques.

In an adaptive Viterbi decoder can be reconfigured dynamically in response to the varying channel conditions so as to reduce power consumption. On the other hand, Viterbi decoders for the trellis-coded modulation (TCM) technique, which involves error-correcting coding and modulation, have been designed and implemented in recent years. The TCM Viterbi decoder requires a greater decoding complexity than the CC Viterbi decoder, thus more efforts must be made to reduce hardware costs. Compared to the traditional Viterbi decoder for convolutional codes and TCM codes, the STTC Viterbi decoder has to perform a

great amount of complex-value multiplications for branch metric computation, which is proportional to the modulation order and the number of antennas.

To overcome this implementation bottleneck, an efficient tree-search algorithm and a constant multiplier architecture is proposed in order to reduce the complexity of branch metric calculation in the STTC Viterbi decoder. The complexity can be reduced to such a degree that the cost of implementation is reasonable compared with the available STBC decoder

II. PROPOSED STTC DECODING ALGORITHM

A. Introduction of Space-Time Trellis Codes

The space-time trellis coded MIMO system, as depicted in Fig. 1, involves modulation, error correction, and diversity techniques. M bits of data are encoded

$$C_t = (c_t^1, c_t^2, \ldots, c_t^m)$$

in the transmitter at time. In the receiver, receiving antennas acquire the signal ,

$$R_t = (r_t^1, r_t^2, \ldots, r_t^{n_R})^T,$$

Which is then decoded by the STTC decoder.

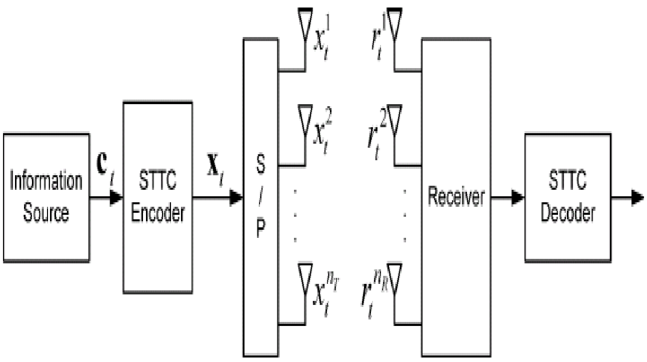

Fig 1. Space time trellis coded MIMO system.

1) STTC Encoder:

The STTC encoder receives m input bit sequences, as shown in Fig. 2.Each bit sequence is buffered with V_k delay elements and encoded with a set of generator coefficients g_i^k similar to the convolutional code for the i -th transmitting antenna, where

$\mathbf{g}_i^k = (g_{0,i}^k, g_{1,i}^k, \ldots, g_{\nu_k,i}^k)$ for the k -th bit equence.

Then, the encoded symbols x_t^i can be expressed by

$$x_t^i = \sum_{k=1}^{m} \sum_{j=0}^{\nu_k} g_{j,i}^k c_{t-j}^k \bmod 2^m,\ i = 1, 2, \ldots, n_T.$$

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FIGURE

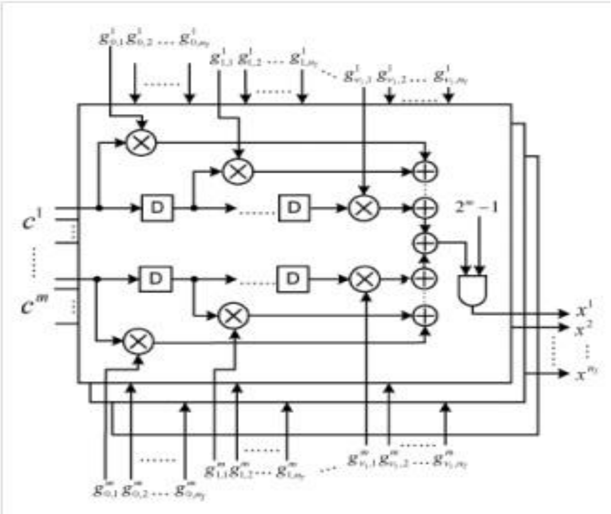

Fig 2 STTC encoder

2) MIMO Channel Mode:

*l*we assume that the encoded symbols are impaired by the Rayleigh fading channel,and the received signal R_t at time t is modeled by

$R_t = H_t X_t + N_t$, where H_t is the $n_R \times n_T$ channel gain matrix and N_t is the noise vector consisting of n_R all white Gaussian variables.

3) STTC Decoder:

The STTC decoder uses the Viterbi algorithm to detect the coded multiple streams that are transmitted through the MIMO channel.

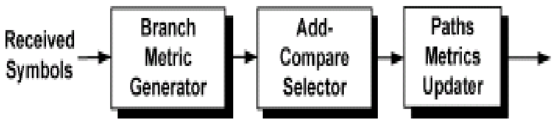

FIGURE 3 Block diagram for the STTC decoder

B. Proposed Branch Metric Calculation Method:

Two methods for branch metric calculation are proposed. Method I performs the branch metric calculation when the channel matrix is updated for each signal vector in the fast fading channel. The Method II computes the branch metrics if the channel remains fixed during a frame period in the slow fading channel.

Method I:

Method I aims to simplify the computational complexity for the branch metrics because a great amount of the complexity lies in the complex-value multiplication $h^t_{j,i}x^i_t$. Method I separates the complex-value multiplication $h^t_{j,i}x^i_t$ into two real-value multiplication equations, $\Re\{h^t_{j,i}\}\Re\{x^i_t\} - \Im\{h^t_{j,i}\}\Im\{x^i_t\}$ and $\Re\{h^t_{j,i}\}\Im\{x^i_t\} + \Im\{h^t_{j,i}\}\Re\{x^i_t\}$. Because the values of $\Re\{x^i_t\}$ and $\Im\{x^i_t\}$ are fixed for a specific candidate symbol, we can easily calculate the product with simple shift-and-add operations. For example, in the 4-PSK STTC code in Appendix , is 1, , or for two transmitters. Its trellis diagram are depicted in Fig. 4. Method I is equivalent to the traditional Viterbi algorithm; thus, the total number of operations is not reduced. However, the constant portion represents the simplified multiplications and occupies almost 50% of the total number of computations. Because the constant multiplications can be implemented using shift-and-add operations, cost and power can be greatly reduced in the VLSI implementation.

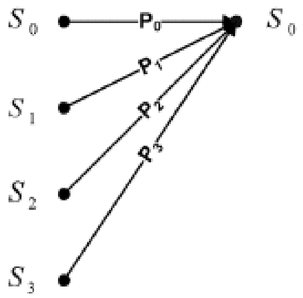

FIGURE 4

2) Method II:

In the slow Rayleigh fading channel, the values of the channel response is constant for a specific time interval; therefore, the value of $h^t_{j,i}x^i_t$ remains fixed in the time interval which is defined as a frame in the generator coefficient determination At the beginning of each frame, the received symbol r^j_t and the 2m channel-impaired candidates ($h^t_{j,i}x^i_t\ (P_j)$) are mapped onto the I/Q plane. The binary-tree structure is determined, as shown in Fig 5

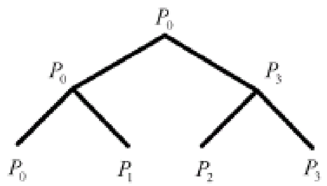

FIGURE 5

D. Complexity Analysis

Fig. 6depicts the computational complexities for 16-QAM under different MIMO configurations. The computational complexities of the proposed branch metric calculation methods are analyzed for the different MIMO configurations.

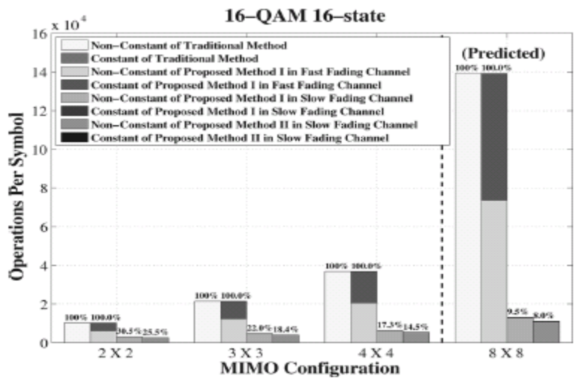

Figure- 6 Computational complexity of 16-QAM modulations

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The computational complexities of the proposed methods have a close relationship with the modulation order and the frame size, as shown in Fig. 7. For Method I, the metric values are computed for each received symbol. Thus, the computational complexity tends to converge as the frame size increases. For Method II, the pre computation of the distances between any two nodes and the bisector equations requires a large amount of complexity in the initially received symbols in a frame.

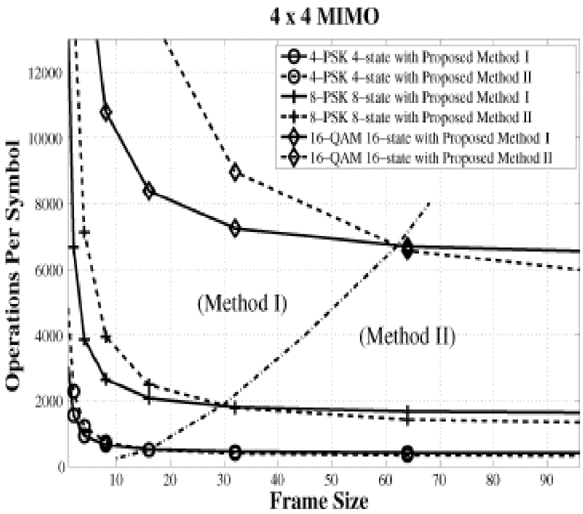

Figure 7 Complexity versus frame size for a 4x4 MIMO

Implementation Report:

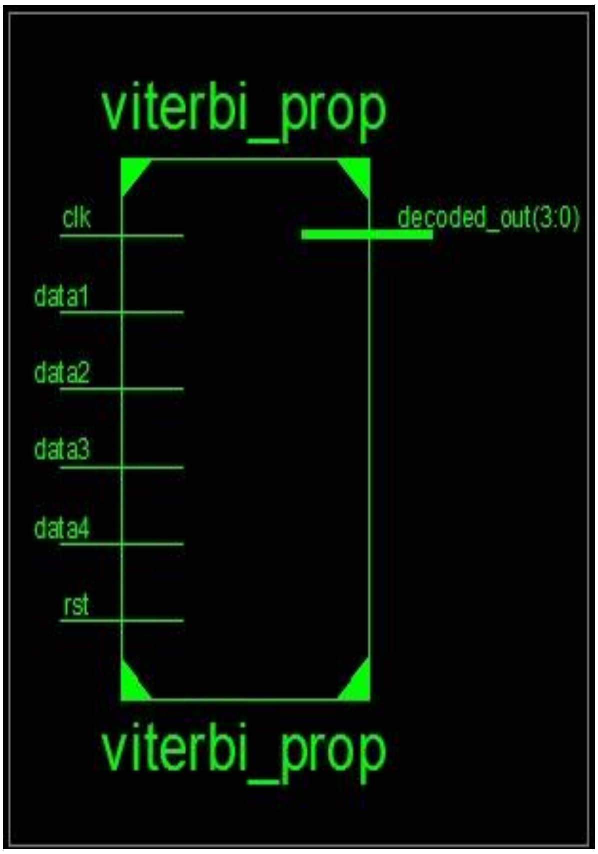

Fig 7: RTL Schematic.

Power Consumption Report:

On-Chip	Power (W)	Used	Available	Utilization (%)
Clocks	0.000	1	---	---
Logic	0.000	192	3840	5.0
Signals	0.000	196	---	---
IOs	0.000	10	173	5.8
Leakage	0.041			
Total	0.041			

Thermal Properties	Effective TJA (C/W)	Max Ambient (C)	Junction Temp (C)
	30.9	83.7	26.3

Supply Source	Summary Voltage	Total Current (A)	Dynamic Current (A)	Quiescent Current (A)
Vccint	1.200	0.010	0.000	0.010
Vccaux	2.500	0.010	0.000	0.010
Vcco25	2.500	0.002	0.000	0.002

	Total	Dynamic	Quiescent
Supply Power (W)	0.041	0.000	0.041

V. CONCLUSION

In this paper, a low-complexity STTC decoding algorithm and its associated hardware architecture are proposed. Method I (Mode I) is designed for fast fading channels and Method II (Mode II) is designed for slow fading channels. The complexity analysis provides the necessary information of the proper method (mode) to be employed under different configurations. In conclusion, an STTC decoder was realized in a silicon chip, which the authors believe can improve the reliability of future coded MIMO communication systems.

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