Hardware Discussion of a MIMO Wireless Communication System Using Orthogonal Space Time Block Codes.

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ABSTRACT

Although multiple-input multiple-output (MIMO) systems have become increasingly popular, the existence of real time results to compare with those predicted by theory is still surprisingly limited. In this work the hardware description of a MIMO wireless communication system using orthogonal space time block codes (OSTBC) is discussed for two antennas at both the transmitter and receiver. A numerical example for a frequency flat time correlated channel is given to show the impact of channel estimation.

KEY WORDS

Multiple-input multiple-output (MIMO), Orthogonal Space Time Block Codes (OSTBC), Blind Detection, Throughput, Rayleigh Fading , Flat Fading

1 Introduction

Multiple-input multiple-output wireless systems have shown increases in ergodic capacity [1, 2]. The problem with achieving capacity is the requirement of infinitely long Gaussian symbols[3]. An alternative method of symbol coding is orthogonal space-time block codes (OSTBC) [4], which exploit diversity by adding redundancy in the time dimension. These codes are practical due to their reasonably small block lengths.

The implementation of MIMO systems up to this point has been done primarily in software such as MATLAB or C++. The channel models simulated in software may not match the behavior of a real-time system. In this work an outline of the hardware implementation of a MIMO system employing STBC is presented.

2 Received Model

A MIMO wireless baseband flat fading communication system with N_r receive antennas and N_t transmit antennas at discrete time k is modeled by

$$\boldsymbol{y}(k) = \boldsymbol{H}(k)\boldsymbol{x}(k) + \boldsymbol{n}(k),$$

where $\boldsymbol{y}$ is the $N_r \times 1$ received vector, $\boldsymbol{x}$ is the $N_t \times 1$ transmitted symbol vector with each x_i belonging to constellation $\mathcal{C}$ with symbol energy E_s, and $\boldsymbol{n}$ is the white noise vector of size $N_r \times 1$ with $n_i \overset{iid}{\sim} \mathcal{CN}(0, N_o)$. The $N_r \times N_t$ channel matrix $\boldsymbol{H}(k) = \{h_{rt}(k)\}$ describes the complex channel gain between the r^{th} receive antenna and the t^{th} transmit antenna.

3 Orthogonal Space-Time Block Codes

For the sake of this discussion, only $N_t = N_r = 2$ will be considered. Let

$$\boldsymbol{X}(m) = \left[\begin{array}{cc} x_1(m) & -x_2^\star(m) \\ x_2(m) & x_1^\star(m) \end{array} \right]$$

be the transmit OSTBC matrix where $m \triangleq 2k$ is the block period. The orthogonality of these codes stems from

$$\boldsymbol{X}(m)^H \boldsymbol{X}(m) = \boldsymbol{X}(m)\boldsymbol{X}^H(m) = ||\boldsymbol{X}(m)||_F^2 \boldsymbol{I}_{N_t}, \tag{1}$$

where $|| \cdot ||_F$ is the Frobenius norm. The receiver exploits this property for channel estimation and symbol decoding .

3.1 Channel Estimation

The transmitter sends pilot symbols for $x_1(m)$ and $x_2(m)$. Assuming the channel varies negligibly over two consecutive symbol periods the received symbol block is

$$\boldsymbol{Y}(m) = \boldsymbol{H}(m)\boldsymbol{X}(m) + \boldsymbol{N}(m),$$

where

$$\boldsymbol{N}(m) = \left[\begin{array}{cc} n_1(k) & n_1(k-1) \\ n_2(k) & n_2(k-1) \end{array} \right].$$

The estimate is formed by [5]

$$\widehat{\boldsymbol{H}}(m) = \boldsymbol{Y}(m)\frac{\boldsymbol{X}^H(m)}{||\boldsymbol{X}(m)||_F^2} = \boldsymbol{H}(m) + \widetilde{\boldsymbol{N}}(m),$$

where $\widetilde{\boldsymbol{N}}(m) = \frac{\boldsymbol{N}(m)\boldsymbol{X}^H(m)}{||\boldsymbol{X}(m)||_F^2}$. Subsequent data symbols are decoded using the most recent estimate.

3.2 Decoding

The receiver gathers $\boldsymbol{y}(m)$ according to [5]

$$\begin{aligned} \boldsymbol{y}(m) = \left[\begin{array}{c} \boldsymbol{y}(k-1) \\ \boldsymbol{y}^\star(k) \end{array} \right] &= \left[\begin{array}{cc} \widehat{h}_{11}(m) & \widehat{h}_{12}(m) \\ \widehat{h}_{21}(m) & \widehat{h}_{22}(m) \\ \widehat{h}_{12}^\star(m) & -\widehat{h}_{11}^\star(m) \\ \widehat{h}_{22}^\star(m) & -\widehat{h}_{21}^\star(m) \end{array} \right] \boldsymbol{x}(m) + \left[\begin{array}{c} n_1(k-1) \\ n_2(k-1) \\ n_1^\star(k) \\ n_2^\star(k) \end{array} \right] \\ &= \widehat{\boldsymbol{H}}_{eff}(m)\boldsymbol{x}(m) + \boldsymbol{n}(m). \end{aligned}$$

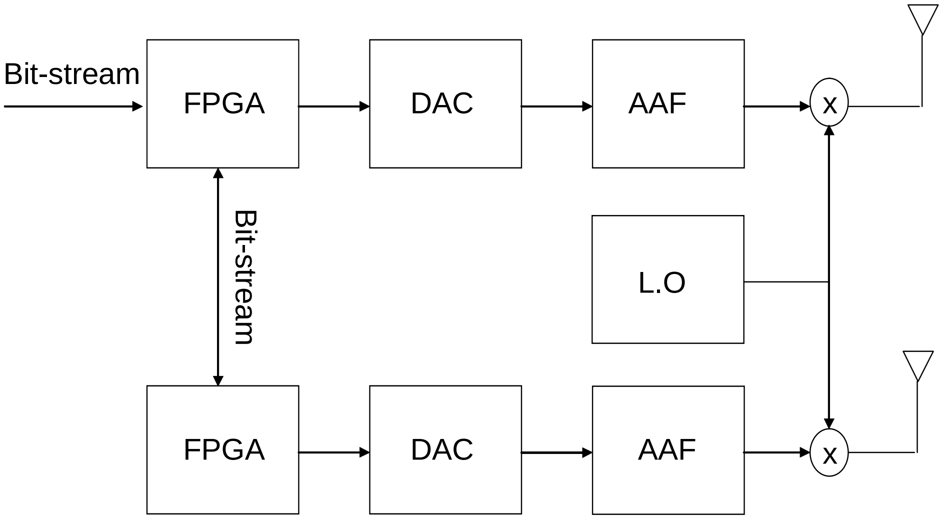

Figure 1: MIMO Transmitter Hardware for $N_t = 2$.

Noting that $\widehat{\boldsymbol{H}}(m)_{eff}^H \widehat{\boldsymbol{H}}(m)_{eff} = ||\widehat{\boldsymbol{H}}(m)||_F^2 \boldsymbol{I}_{N_t}$, the decoupled received symbol vector is

$$\boldsymbol{z}(m) = \widehat{\boldsymbol{H}}_{eff}(m)^H \boldsymbol{y}(m) = ||\widehat{\boldsymbol{H}}(m)||_F^2 \boldsymbol{x}(m) + \widetilde{\boldsymbol{n}}(m),$$

where $\widetilde{\boldsymbol{n}}(m) = \widehat{\boldsymbol{H}}_{eff}(m)^H \boldsymbol{n}(m)$. The minimum distance decision is

$$\widehat{x}_i(m) = \arg\min_{x_i \in \mathcal{C}} ||z_i(m) - ||\widehat{\boldsymbol{H}}(m)||_F^2 x_i||^2 \quad i = 1, 2.$$

4 MIMO Transmitter Block Diagram

The block diagram for the MIMO transmitter is illustrated in Figure 1. The bit-stream is fed into the both FPGA chips for OSTBC construction, digital modulation and pulse shaping. Next, they are converted to analog, passed through an anti-aliasing filter, up-converted to the carrier frequency, and launched into the wireless environment.

5 MIMO Receiver Block Diagram

A block diagram describing the MIMO receiver is displayed in Figure 2. The received RF signal is passed through a image rejection filter, down converted to the intermediate frequency, and low pass filtered to prevent amplifier clipping due to high-frequency energy. From here the signal is digitized, transferred to a high rate disk drive, and sent to a baseband MIMO OSTBC receiver implemented in MATLAB.

6 Numerical Example

To give some insight into the performance capability of the MIMO OSTBC system an example is given. The channel is assumed to be frequency flat with time correlation according to Jakes model [6]. The autocorrelation function of each sub-channel satisfies

$$R_{h_{mn}h_{mn}}(\tau) = J_0(2\pi f_d T_s),$$

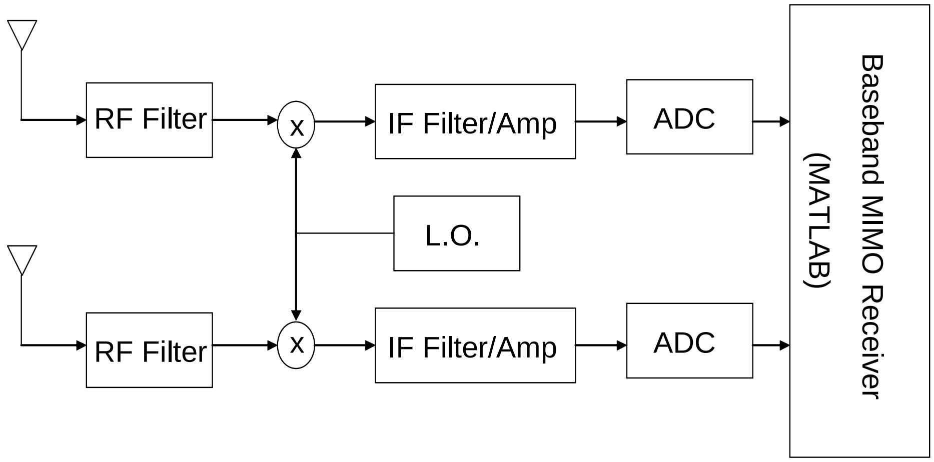

Figure 2: MIMO Receiver Block Diagram for $N_r = 2$.

where f_d is the doppler frequency and T_s is the symbol period. The parameters held constant are displayed in Table 1. The SER for $f_dT_s = .0005, .005,$ and $.1$ are respectively plotted in Figures 3,4, and 5. Three different operating modes at the receiver are considered: full channel knowledge, estimation every 2 blocks, and estimation every four blocks. As f_dT_s is increased, the performance deteriorates more significantly when the receiver waits longer to estimate, resulting in a tradeoff between throughput and SER.

7 Conclusion

A hardware implementation of a 2×2 MIMO OSTBC system using BPSK was presented. The transmitter hardware and receiver block diagram were analyzed. A numerical example was given to investigate the relationship between throughput and reliability. The SER was shown to deteriorate when the receiver prolongs channel estimation in favor of decoding. This behavior became more relevant when the normalized doppler frequency was increased.

Table 1: Parameters Values for numerical example

Parameter	Value	Description
N_r	2	Receive Antennas
N_t	2	Transmit Antennas
E_s	1	Energy per Symbol
M	2	Constellation size (BPSK)
N_s	1e5	Number of symbols

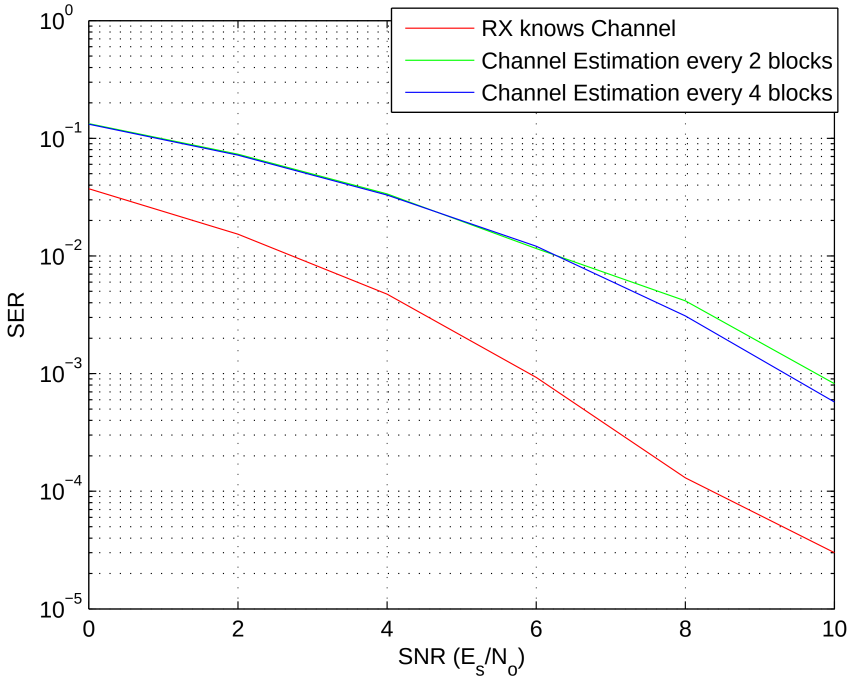

Figure 3: SER for a 2x2 MIMO system when $f_d T_s = 0.0005$.

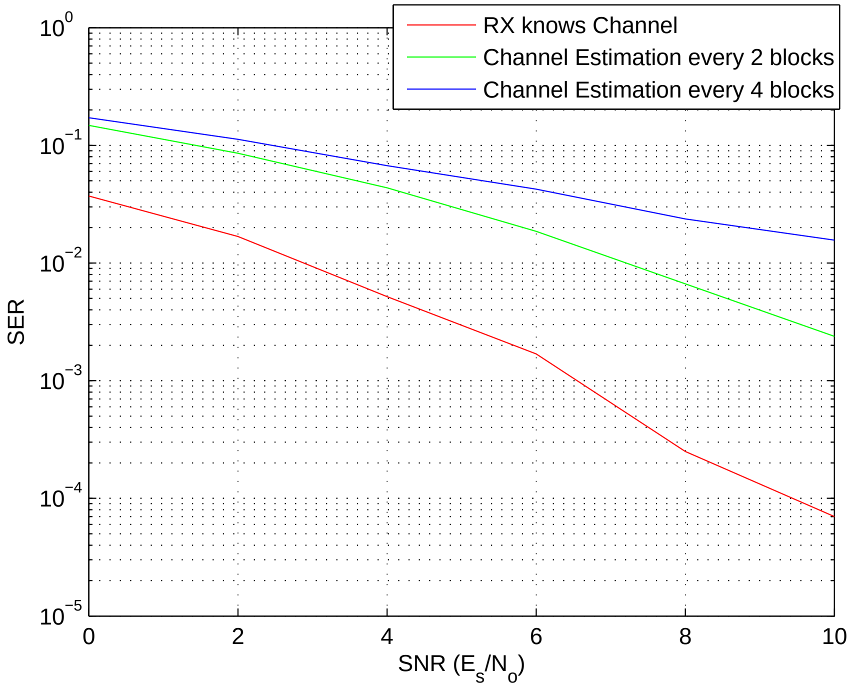

Figure 4: SER for a 2x2 MIMO system when $f_d T_s = 0.05$.

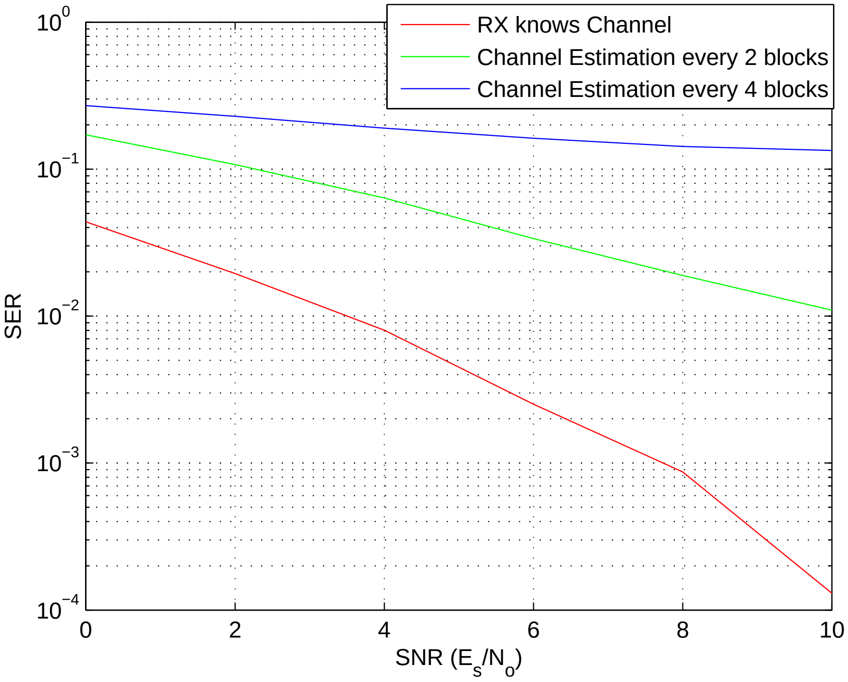

Figure 5: SER for a 2x2 MIMO system when $f_d T_s = 0.1$.

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