Implementation of Alamouti 2X3 Code on FPGA Board

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ABSTRACT

MIMO systems with multiple antenna elements at both Transmitter and Receiver ends are an efficient solution for future wireless communication systems. They provide high data rates by exploiting the spatial domain under the constraints of limited bandwidth and transmit power. Space-Time Block Coding is a MIMO transmit strategy which exploits transmit diversity and high reliability. In the present paper performance analysis and a comparative study is reported for Alamouti code using transmit-receive diversity (2x1, 2X2, 2x3) with maximum likelihood detection technique. The channel is assumed to be flat Rayleigh fading channel and noise samples are independent with zero mean complex Gaussian random variable. The Alamouti Space Time Block codes with modulation techniques BPSK, QPSK and 16-QAM are used to obtain the bit error rate performance under different SNR scenarios. The results reported in this paper suggest substantial improvement in the system performance by incorporating multiple input multiple output techniques in order to improve the link quality.

Key words: Alamouti code, Multiple Input and Multiple output (MIMO), FPGA,OSTBC, MRRC, SNR, BER.

1. Introduction

The idea of Multi-Antenna systems in a wireless communication link opens a new dimension in reliable communication and also improves the system performance substantially. They use more channels each of the individual transmission channels is still limited according to Shannon–Hartley equation,

$$C=B\ log_2(1+SNR)$$

Where B is transmission band width transmission bandwidth and SNR is the signal to noise ratio of the channel. This equation gives the absolute maximum capacity of the channel. So the only way to increase the capacity of the communications system is to increase the bandwidth used in transmission, or to increase SNR. But here with multiple antenna systems the overall capacity of the system is the sum of the capacities of the individual channels. Physical modeling of a MIMO channel cannot lead to space-time coding design criteria. Mathematical modeling is necessary. The simplest mathematical model for ant× nr MIMO channel is

$$y = Hx+n$$

Multi-path propagation occurs when there are multiple transmission paths between the transmitter and the receiver. In a traditional single antenna system multi-path propagation can be a problem as it causes Inter-Symbol Interference. Whereas Multi-Antenna systems use multi-path propagation to their benefit, and in fact rely on some amount being present. Constructive and destructive interference can occur at the receiver. When destructive interference occurs, the signal power can be significantly diminished. This phenomenon is called fading, one essential problem of the wireless channel; the performance of a system (in terms of probability of error) can be severely degraded by fading. Fading can be mitigated by diversity, the antenna diversity, which means that, the information is transmitted not only once but several times, and received by multiple antennas at different time instances hoping that at least one of the replicas will not undergo severe fading. A diversity technique makes use of an important property of wireless MIMO channels. The different signal paths can be often modeled as a number of separate, independent fading channels. In order to evaluate the effectiveness of a given channel coding and processing technique before construction, some model of the channel must be developed that adequately describes the environment. Such analysis reduces the cost of developing a complex system by reducing the amount of hardware that has to be developed for evaluation of performance. The channel model made here use Rayleigh fading channel. Rayleigh fading is a statistical model for the effect of a propagation environment on radio signal, used by wireless devices. Rayleigh fading models assume that the magnitude of a signal that has passed through will vary randomly, or fade, according to a Rayleigh distribution — the radial component of the sum of two uncorrelated Gaussian random variables. Rayleigh fading is viewed as a reasonable model for tropospheric and ionospheric signal propagation as well as the effect of heavily built-up urban environments on radio signals. Rayleigh fading is most applicable when there is no dominant propagation along a line of sight between the transmitter and receiver.

- The net gain is the sum of all closely delayed paths:
- $Re^{2\emptyset} = \sum_{n=1}^{\infty} \alpha_n e^{j\theta_n} = \sum_{n=1}^{\infty}(x_n + jy_n) = g = g_{real} + jg_{imag}$
- Each of g_{real} and g_{imag} is the sum of many independent random variables.

Fading gain $g = g_{real} + jg_{imag}$ is complex Gaussian with zero mean and variance $2\sigma^2$ [1].Several transmission schemes have been proposed that utilize the MIMO channel in different ways, such as spatial multiplexing, space-time coding or beam forming. Space-time coding (STC), introduced first by Tarokh at el. is promising methods where the number of the transmitted code symbols per time slot are equal to the number of transmit antennas[2]. These code symbols are generated by the (space time block codings)STBCs can be divided into two main classes, namely, OSTBCs andNon-OSTBCs. The OSTBCs achieve full diversity with low decoding complexity, but at the price of some loss in data rate. Full data rate is achievable in connection with full diversity only [3].

2. Alamouti code

Alamouti is the simplest of all the STBCs. It was designed for a two-transmitter and one-receiver antenna system. It takes two time-slots to transmit two symbols. Alamouti code can be generalized to an arbitrary number of receiver antennas [4]. Alamouti scheme is simplein coding and decoding making this very useful for real-world implementation. The simplest Alamouti 2x1 code is used as base and improved to 2x3. This showed improved results in BER and SNR when tested for different digital modulation systems of BPSK, QPSK and 16-QAM.

3. Mathematical Derivation of Alamouti 2x3 code

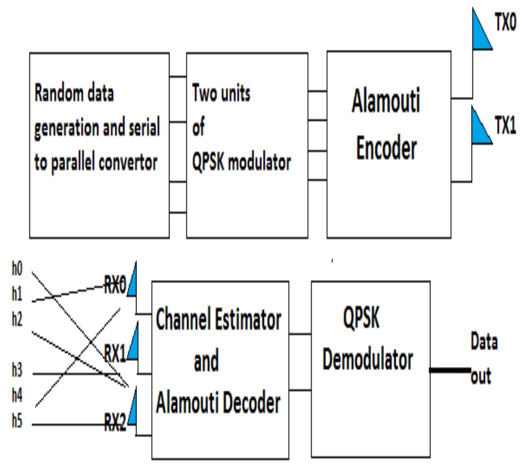

Fig 1 : Block diagram of the design

Table 1: The traditional Alamoutitransmission matrix can be represented as follows:

	T	T+t
Tx_0	S_0	$-S_1^*$
Tx_1	S_1	S_0^*

The channel combining matrix is represent as follows for the 2x3 scheme which is to be implemented on FPGA board in this paper. (The channel gains are represented using 'h')

	Rx_0	Rx_1	Rx_2
Tx_0	h_0	h_2	h_4
Tx_1	h_1	h_3	h_5

The equations for the channel gains for the six paths of the transmitted bits can be represented by the following equations in terms of the time and the phase shifts:

$$h_0(t) = h_0(t+T) = h_0 = \alpha_0 e^{-i\theta_0}$$

$$h_1(t) = h_1(t+T) = h_1 = \alpha_1 e^{-i\theta_1}$$

$$h_2(t) = h_2(t+T) = h_2 = \alpha_2 e^{-i\theta_2}$$

$$h_3(t) = h_3(t+T) = h_3 = \alpha_3 e^{-i\theta_3}$$

$$h_4(t) = h_4(t+T) = h_4 = \alpha_4 e^{-i\theta_4}$$

$$h_5(t) = h_5(t+T) = h_5 = \alpha_5 e^{-i\theta_5}$$

At receiver side

	T	T+t
Rx_0	r_0	r_1
Rx_1	r_2	r_3
Rx2	r4	r5

$$r_0 = h_0 s_0 + h_1 s_1 + n_0$$

$$r_1 = -h_0 s_1^* + h_1 s_0^* + n_1$$

$$r_2 = h_2 s_0 + h_3 s_1 + n_2$$

$$r_3 = h_0 s_1^* + h_3 s_0^* + n_3$$

$$r_4 = h_4 s_0 + h_5 s_1 + n_4$$

$$r_5 = -h_4 s_1^* + h_5 s_0^* + n_5$$

Where n_0, n_1, n_2, n_3, n_4, n_5 are complex random variables representing receiver thermal noise and interference. The output after recombining

$$\tilde{s_0} = h_0^* r_0 + h_1 r_1^* + h_2^* r_2 + h_3 r_3^* + h_4^* r_4 + h_5 r_5^*$$

$$\tilde{s_0} = -h_0 r_1^* + + h_1^* r_0 - h_2 r_3^* + h_3^* r_2 - h_4 r_5^* + h_5^* r_4$$

Substituting r_0, r_1, r_2, r_3, r_4, r_5 in above two equations results as follows:

$$\tilde{s_0} = (\alpha_0^2 + \alpha_1^2 + \alpha_2^2 + \alpha_3^2 + \alpha_4^2 + \alpha_5^2) s_0 + h_0^* n_0 + h_1 n_1^* + h_2^* n_2 + h_3 n_3^* + h_4^* n_4 + h_5 n_5^*$$

$$\tilde{s_1} = (\alpha_0^2 + \alpha_1^2 + \alpha_2^2 + \alpha_3^2 + \alpha_4^2 + \alpha_5^2) s_1 + h_1^* n_0 - h_0 n_1^* + h_3^* n_2 - h_4 n_5^* + h_5^* n_4 - h_2 n_3^*$$

These combined signals are then sent to the maximum likelihood decoder. Signal$s_0$uses the decision criteria as below,

Chooses_i if

$$(a_0^2 + a_1^2 + a_2^2 + a_3^2 + a_4^2 + a_5^2 - 1)\|s_i\|^2 + d^2(\tilde{s_1}, s_i) \le (a_0^2 + a_1^2 + a_2^2 + a_3^2 + a_4^2 + a_5^2 - 1)\|s_k\|^2 + d^2(\tilde{s_1}, s_k)$$

Choose$s_i$if

$$d^2(\tilde{s_0}, s_i) \le d^2(\tilde{s_0}, s_k) \qquad \forall i \ne k$$

Similarly for s_1 using the decision rule is to choose signal s_i if

$$(a_0^2 + a_1^2 + a_2^2 + a_3^2 + a_4^2 + a_5^2 - 1)\|s_i\|^2 + d^2(\tilde{s_1}, s_i) \le (a_0^2 + a_1^2 + a_2^2 + a_3^2 + a_4^2 + a_5^2 - 1)\|s_k\|^2 + d^2(\tilde{s_1}, s_k)$$

or for PSK signals, choose s_i if

$$d^2(\widetilde{s_0}, s_i) \leq d^2(\widetilde{s_0}, s_k) \qquad \forall i \neq k$$

The combined signals are equivalent to that of six branches MRRC. Therefore, the resulting diversity order from the new two-branch transmits diversity scheme with three receivers which is equal to that of the six branch MRRC scheme.

4. Hardware implementation

Both the transmitting and receiving designs have been synthesized and tested on a single FPGA board. In order to test their functionality, models have been used to establish an end-to-end wireless link [5]. The type of board used for implementation is an ALTERA FPGA De0 board and simulated verilog programs and implemented them using the softwares 'ModelSim and 'Quartus II'. The two transmitter antennas and three antennas at the receiver with the encoding and decoding algorithms are coded successfully using Verilog Hardware Description Language (HDL) and verified. The inclusion of an Alamouti encoder in a transmitter design does not significantly increase its complexity. In fact, the hardware realization differs very little from the implementation of two standard wireless transmitters. The only operation the Alamouti encoder performs on modulated symbols is the negation of either the real or imaginary part of a symbol. For most constellations, this process is analogous to mapping one symbol to another valid symbol. The output of the encoding process is two streams of modulated symbols [6]. The implementation of an Alamouti receiver is somewhat more challenging. Some of these challenges were due to the constraints in implementing it on the FPGA as had to make sure that the FPGA had sufficient amount of multiplication resources available. The Alamouti decoder design implemented multiplies simply using the simple '*' operator in Verilog HDL.

5. Results and Discussions:

The verification of the functionality of the 2x3 alamouti scheme thus developed is done by comparing the simulation results of the previously existing schemes of alamouti diversity techniques namely 2x1 and 2x2 with now developed 2x3 scheme using MATLAB. Modulation technique is chosen after testing the above stated schemes with different modulation techniques as BPSK, QPSK and 16-QAM [7]. Simulation results of those techniques are shown below by plotting BER vs SNR for different schemes. In general the Bit Error Rate is measured by the distance between two nearest possible signal points in the signal space diagram (constellation diagram) as the distance between two points decreases the possibility of error increases. It is observed that M-ary QAM out performs the corresponding M-ary PSK in probability of BER for M>8 with slightly decrease in average performance [8].

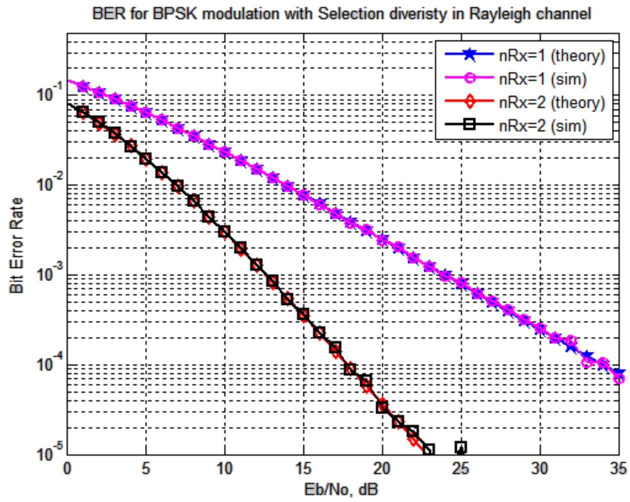

Fig 2: plot for BER vs SNR for 2x1 and 2x2 for BPSK

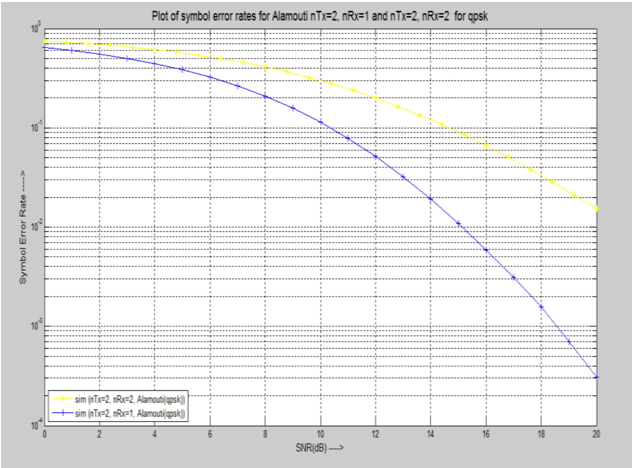

Fig 3: Plot for BER vs SNR for 2x1 and 2x3 for QPSK

The observation of the obtained simulation results clearly describes the reducing BER with increase in the order of receiver diversity. Now the focus is on testing which modulation technique gives the best results for the data to be encoded with least possible error rates. Hence, the comparison can be observed as can be seen in Figures. 3 and 4.

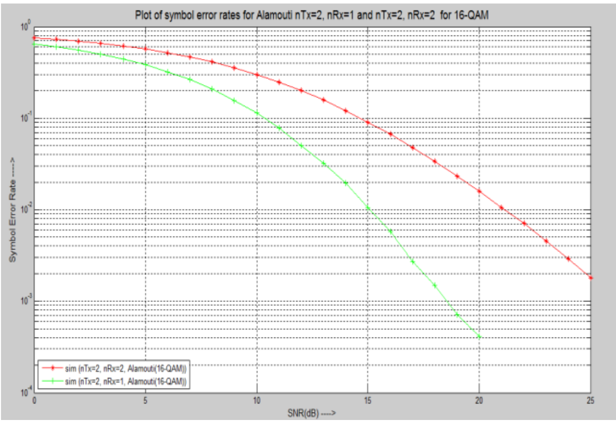

Fig 4: plot for BER vs SNR for 2x1 and 2x3 for 16 QAM

The test results show the better functionality of 2x2 than the conventional 2x1 scheme andas expected, better results with 2x3scheme. Hence thenew 2x3 code is implemented on FPGA board and tested in practical functionality.

6. CONCLUSIONS

An extension in orthogonal Space Time Block code, Alamouti code, to two transmitter and three receiver antenna in wireless communication system is successfully modeled in three different methods namely mathematical derivation, using MATLAB code, in verilog and finally extending the work to hardware (FPGA) implementation. All the work done here is with an assumption that the channel is Rayleigh and stationary over a single bit rate. The Alamouti (2x3, 2x2, 2x1) code is tested in MATLAB using digital modulation techniques of BPSK, QPSK and 16 – QAM. Thus with all the derived results with the help of theoretically conclusions, mathematical derivations, MATLAB simulations and hardware implementation the work can be concluded that 2X3 Alamouti code in MIMO systems is giving an high data rate showing an improvement in BER and SNR when compared to earlier versions of antenna diversity using Alamouti code.

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