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Implementation of STBCfor MIMOBased on Alamouti Principle

Dr G Ravikumar
Associate Professor, Department of ECE
Sri Sai Institute of Technology and Science, Rayachoti
Email: ravikumargphd@gmail.com

Abstract – Realization of multi input and multi output (MIMO) systems is highly essential for Wimax networks. Space–time block coding is a technique used in wireless communications to transmit multiple copies of a data stream across a number of antennas and to exploit the various received versions of the data to improve the reliability of data-transfer.

In wireless communications the transmitted signal must traverse a potentially difficult environment with scattering, reflection, refraction and so on and may then be further corrupted by thermal noise. In the receiver STBC redundancy results in a higher chance of being able to use one or more of the received copies to correctly decode the received signal. The space–time coding combines all the copies of the received signal in an optimal way to extract as much information from each of them as possible.

In this project a computationally efficeint algorithm for space time block decoding will be implemented for FPGA based applications. The VHDL will be used for realization of the decoding alogrithm and other communication blocks.

The algorithm will be realized for Phase Shift Keying modulation (BPSK) scheme. The STBC encoder will also be realized in MATLAB/OCTAVE which generates the required appropriate codes for decoder. The work involves FPGA implementation of STBC decoder, and demodulator. Various sub blocks such as SIN/COS generators, multipliers, adders, encoding look up tables, complex arithmetic units etc will be implemented. These blocks will be realized in generic style to ensure scalability and reconfigurability of the STBC decoder design.

Modelsim xilinx edition (MXE) tool will be used for simulation and functional verification. Xilinx Synthesis technology (XST) will be used for FPGA synthesis. Timing analysis will be carried out to predict the maximum acheviable clock speeds for choosen Xilinx sparatan 3E FPGA device.

Introduction

Nowadays, there is a growing demand for providing high data rates and transmission quality in the condition of limited spectral resource and power consumption. With these requirements, several new technologies emerge, such as multiple-input multipleoutput (MIMO) technology, cooperative communication, ultra wideband (UWB) and cognitive radio.

Space-time coding as a primary MIMO technique which uses multipleantennas at both the transmitter and receiver sides are well known for its ability to resist the influence of wireless fading channel and provide higher capacity and better system performance than single link systems in wireless communications. Recently, it has been demonstrated that user-cooperation represents an effective way to introduce spatial diversity in wireless scenarios where we can not take the full benefit of the uncorrelated channels from the multi-antenna systems. Cooperative diversity gains can be achieved through creating distributed virtual antennas across different terminals in the network. Taking advantage of the rich wireless propagation environment across multiple protocol layers in network architecture, we can obtain numerous opportunities to dramatically improve network performance. The theoretical analysis of such cooperative systems has attracted significant interests and the study of practical architectures is a fertile area of research.

In Cooperative communication system each relay can play as a virtual antenna of the source. Laneman gave the basic algorithm and architecture of cooperative communication in his thesis. In this section, we present the computer simulation results about the STBC based cooperative communication systems. Virtual Alamouti STBC theory is employed in all these different cases. Slow Rayleigh fading channel and ideal channel estimation are assumed in the simulation. BPSK modulation and MRC/MLD receiver are applied.

In this paper, we investigate the STBC based multi-antenna cooperative systems and provide the corresponding simulated performance under slow Rayleigh fading channel.

Multi- Input Multi Output (MIMO):

In radio, multiple-input and multiple-output, or MIMO is the use of multiple antennas at both the transmitter and receiver to improve communication performance. It is one of several forms of smart antenna technology. Note that the terms input and output refer to the radio channel carrying the signal, not to the devices having antennas.

MIMO technology has attracted attention in wireless communications, because it offers significant increases in data throughput and link range without additional bandwidth or transmit power. These business companies permit of facilitate their clients to use them for free. These business companies permit of facilitate their clients to use them for free. WiFi also rolled out for similar aims but WIMAX offer enhanced Quality of Service WiFi also rolled out for similar aims but WIMAX offer enhanced Quality of Service It achieves this by higher spectral efficiency (more bits per second per hertz of bandwidth) and link reliability or diversity (reduced fading).

Because of these properties, MIMO is an important part of modern wireless communication standards such as IEEE 802.11n (Wifi), 4G, 3GPP Long Term Evolution, WiMAX and HSPA+.

History of MIMO:

Wireless standards

In the commercial arena, Iospan Wireless Inc. developed the first commercial system in 2001 that used MIMO with Orthogonal frequency-division multiple access technology (MIMO-OFDMA). Such private networks are expected to be the very last WIMAX application. Iospan technology supported both diversity coding and spatial multiplexing. In 2005, Airgo Networks had developed an IEEE 802.11n precursor implementation based on their patents on MIMO.

Following that in 2006,several companies (including at least Broadcom, Intel, and Marvell) have fielded a MIMO-OFDM solution based on a pre-standard for 802.11n WiFi standard. Also in 2006, several companies (Beceem Communications, Samsung, Runcom Technologies, etc.) have developed MIMO-OFDMA based solutions for IEEE 802.16eWiMAX broadband mobile standard. All upcoming 4G systems will also employ MIMO technology. Several research groups have demonstrated over 1 Gbit/s prototypes.

Functions of MIMO :

MIMO can be sub-divided into three main categories

Precoding

It is multi-stream beamforming, in the narrowest definition. In more general terms, it is considered to be all spatial processing that occurs at the transmitter. In (single-layer) beamforming, the same signal is emitted from each of the transmit antennas with appropriate phase (and sometimes gain) weighting such that the signal power is maximized at the receiver input. The benefits of beamforming are to increase the received signal gain, by making signals emitted from different antennas add up constructively, and to reduce the multipath fading effect. In the absence of scattering, beamforming results in a well defined directional pattern, but in typical cellular conventional beams are not a good analogy.

When the receiver has multiple antennas, the transmit beamforming cannot simultaneously maximize the signal level at all of the receive antennas, and precoding with multiple streams is used. Because it offers significant increases in data throughput and link range without additional bandwidth or transmit power. These business companies permit of facilitate their clients to use them for free. Note that precoding requires knowledge of channel state information (CSI) at the transmitter.

Spatial multiplexing

It requires MIMO antenna configuration. In spatial multiplexing, a high rate signal is split into multiple lower rate streams and each stream is transmitted from a different transmit antenna in the same frequency channel. If these signals arrive at the receiver antenna array with sufficiently different spatial signatures, the receiver can separate these streams into (almost) parallel channels. Spatial multiplexing is a very powerful technique for increasing channel capacity at higher signal-to-noise ratios (SNR). The maximum number of spatial streams is limited by the lesser in the number of antennas at the transmitter or receiver. Spatial multiplexing can be used with or without transmit channel knowledge. Spatial multiplexing can also be used for simultaneous transmission to multiple receivers, known as space-division multiple access. By scheduling receivers with different spatial signatures, good separability can be assured.

Diversity Coding

These techniques are used when there is no channel knowledge at the transmitter. In diversity methods, a single stream (unlike multiple streams in spatial multiplexing) is transmitted, but the signal is coded using techniques called space-time coding. The signal is emitted from each of the transmit antennas with full or near orthogonal coding.

Diversity coding exploits the independent fading in the multiple antenna links to enhance signal diversity. The maximum number of spatial streams is limited by the lesser in the number of antennas at the transmitter or receiver. Because there is no channel knowledge, there is no beamforming or array gain from diversity coding.

Spatial multiplexing can also be combined with precoding when the channel is known at the transmitter or combined with diversity coding when decoding reliability is in trade-off.

Forms of MIMO:

1.4.3 Applications of MIMO:

Spatial multiplexing techniques makes the receivers very complex, and therefore it is typically combined with Orthogonal frequency-division multiplexing (OFDM) or with Orthogonal Frequency Division Multiple Access (OFDMA) modulation, where the problems created by multi-path channel are handled efficiently. The IEEE 802.16e standard incorporates MIMO-OFDMA. The IEEE 802.11n standard, released in October 2009, recommends MIMO-OFDM.

MIMO is also planned to be used in Mobile radio telephone standards such as recent 3GPP and 3GPP2 standards. The maximum number of spatial streams is limited by the lesser in the number of antennas at the transmitter or receiver. In 3GPP, High-Speed Packet Access plus (HSPA+) and Long Term Evolution (LTE) standards take MIMO into account. Moreover, to fully support cellular environments MIMO research consortia including IST-MASCOT propose to develop advanced MIMO techniques, i.e., multi-user MIMO (MU-MIMO).

MIMO technology can be used in non-wireless communications systems. One example is the home networking standard ITU-T G.9963, which defines a powerline communications system that uses MIMO techniques to transmit multiple signals over multiple AC wires (phase, neutral and ground).

Space Time Block Coding (STBC):

It is a technique used in wireless communications to transmit multiple copies of a data stream across a number of antennas and to exploit the various received versions of the data to improve the reliability of data-transfer. The fact that transmitted data must traverse a potentially difficult environment with scattering, reflection, refraction and so on and, as well as, be corrupted by thermal noise in the receiver means that some of the received copies of the data will be "better" than others. This redundancy results in a higher chance of being able to use one or more of the received copies of the data to correctly decode the received signal. In fact, STBC combines all the copies of the received signals in an optimal way to extract as much information from each of them as possible.

Maximum likelihood estimation:

It was none other than R. A. Fisher who developed maximum likelihood estimation. Fisher based his work on that of Karl Pearson, who promoted several estimation methods, in particular the method of moments. While Fisher agreed with Pearson that the method of moments is better than least squares, Fisher had an idea for an even better method. It took many years for him to fully conceptualize his method, which ended up with the name maximum likelihood estimation.In 1912, when he was a third year undergraduate student, Fisher published a paper called "Absolute criterion for fitting frequency curves."

The concepts in this paper were based on the principle of inverse probability, which Fisher later discarded. Because Fisher was convinced that he had an idea for the superior method of estimation, criticism of his idea only fueled his pursuit of the precise definition. In the end, his debates with other statisticians resulted in the creation of many statistical terms we use today, including the word "estimation" itself and even "statistics". Finally, Fisher defined the difference between probability and likelihood and put his final touches on maximum likelihood estimation in 1922.

Mathematical Theory of Maximum Likelihood Estimation:

Suppose we have flipped a coin three times and observed a sequence of events HHT. We know that flipping a coin is modeled by the binomial probability density function,

$$P(k;n,p) = \binom{n}{k} p^k (1-p)^{n-k},$$

eqn.......(1.6.1)

where we have *k* successes out of *n* Bernoulli trials and we define the random variable *K* as either "heads" or "not heads" on each toss. The parameter of this model is *p*, the probability of flipping a coin and getting heads. So we define

$$P(K=1) = p$$

$$P(K=0) = (1-p)$$

For our sequence HHT K1 = 1, K2 = 1, and K3 = 0, and since these trials are independent, we get

$$P(K_1 = 1 \cap K_2 = 1 \cap K_3 = 0) = P(K_1 = 1) \cdot P(K_2 = 1) \cdot P(K_3 = 0)$$

eqn.......(1.6.2)

which means ,

$$P(K_1 = 1 \cap K_2 = 1 \cap K_3 = 0) = p^2(1-p)$$ eqn.......(1.6.3)

Based on this data set, a good estimate for the mean of the binomial model is $\frac{2}{3}$ since

$$P(k) = \binom{n}{k} \frac{2}{3}^k \left(\frac{1}{3}\right)^{n-k}$$

eqn.......(1.6.4)

is much more likely to predict HHT than

$$P(k) = \binom{n}{k} \frac{1}{2}^k \left(\frac{1}{2}\right)^{n-k}$$

eqn.......(1.6.2)

which is what we might have expected since most coins have a probability of getting heads of one half. But in this case, based on our known data, we expect to get heads two thirds of the time on future tosses with the same coin.

Properties of Estimators:

The maximum likelihood estimator is just one of an infinite number of estimators. Perhaps, like Fisher we want to compare estimators to see if we can determine which one is best.

Since we have made sure to define an estimator as a random variable,then they each have their own expected value, and variance which allow us to make comparisons.

While with a point estimate you have no way of knowing how precise it is, with estimators you can specify a confidence interval. The larger the sample size, the greater the precision of the estimator. The experimental design can incorporate the necessary sample size to provide the desired amount of precision.

OVERVIEW OF ALAMOUTI SCHEME

The Alamouti scheme is the only orthogonal space-time block code using complex signals for two transmit antennas which provides full diversity of 2 and full rate of 1. For more 2010 Fifth IEEE International Symposium on Electronic Design, Test & Applications than two transmit antennas, the goal is to design transmission codes that achieve full diversity at the highest possible rate with low decoding complexity. In our 2×2 MIMO implementation, we use two distinct training codes over 2 time multiplexed preamble slots at the transmitter. When one transmitter is sending training data in one time slot, the other is off. These 26-bit preambles are GSM training sequence codes (TSC) 0 and 1 [11]. The two transmitters then transmit 128 space-time encoded data symbols simultaneously before the cycle repeats. At the transmitter, the SASRATS transmitters are programmed to run a 2 transmit Alamouti encoding scheme, where two symbols, $s0$ and $s1$, are transmitted simultanously from two transmitters at time instant t. At time instant $t + T$, the symbols $-s_1^*$ and s_0^* are transmitted simultanously from the transmitters where * represents the complex conjugate. The transmission matrix is represented by

$$S = \begin{bmatrix} s_0 & s_1 \\ -s_1^* & s_0^* \end{bmatrix}$$

eqn.......(2.1)

The transmitted symbols travel through 2 independent channels $h0$ and $h1$ to a receiver where noises $n0$ and $n1$ are added to the received signals. $h0$ and $h1$ are complex multiplicative distortions assumed constant across two consecutive symbols.

The complexity of the combiner and ML detector depends on type of modulation. Binary phase shift keyed (BPSK) symbols are the simplest to detect. Detection of non equal energy modulation schemes require channel estimates in the ML detector and has higher complexity. The present work considers BPSK and QPSK implementations only.

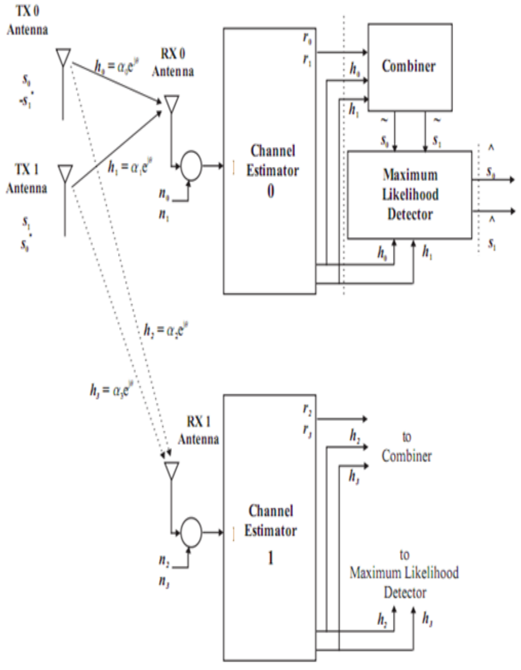

Diagram 2. Block diagram of alamouti decoding implementation

Implementation of a MIMO 2 transmitter and 2 receiver Alamouti system, requires the estimation of 4 channel $(\hat{h}_0, \hat{h}_1, \hat{h}_2 \text{ and } \hat{h}_3)$, 2 at each receiver as shown in Figure 2.1. In this situation, the output of combiner yields 2 outputs.

$$\tilde{s}_0 = \hat{h}_0^* r_0 + \hat{h}_1 r_1^* + \hat{h}_2^* r_2 + \hat{h}_3 r_3^* \quad \text{eqn.......(2.2)}$$

where $\hat{h}_2$ and $\hat{h}_3$ are channel estimates from the second receiver. In the case of a 2×2 Alamouti implementation using PSK signals, the ML decoder remains unchanged except for the combiner. The combiner output $\tilde{s}_0$ is actually the sum of $\tilde{s}_0$ from receiver 0 and $\tilde{s}_0$ from receiver 1. Likewise, $\tilde{s}_1$ is actually the sum of $\tilde{s}_1$ from receiver 0 and $\tilde{s}_1$ from receiver 1. Thus a $2 \times M$ Alamouti implementation can be easily implemented by summing together the appropriate combiner outputs from *M* receivers before feeding one ML detector. In an extended version of Alamouti for 4 transmitters , full rate is achieved but the system is half rank (quasi-orthogonal) with some loss in diversity as transmitted symbols cannot be fully decoupled. Tarokh's STBC scheme for 4 transmitters on the other hand, achieves complete orthogonality at half the full rate. Tarokhs scheme suffers no loss in diversity and receiver decoding is simpler as the transmitted symbols can be fully decoupled.

The complete design is implemented using a top down hierarchical schematic entry approach on the *Xilinx Integrated System Enviroment (ISE) Foundation* design tool.

VHDLcode can also be integrated as a block with other schematiccomponents if desired. We have also made extensive use*n* of various *Xilinx Core Generator* intellectual property(IP)modules incorporated within the ISE Foundation toolset toshorten design cycle time.

CONCLUSION

We have described the implementation of a real time maximum likelihood Alamouti decoder for use on our MIMO platform implemented on an FPGA using the Xilinx ISE tool and Core Generator IP modules. We have also experimentally verified the operation of the decoder in a closed Alamouti 2×1 diversity scheme using an RF channel simulator and also in an open 2×2 and 2×4 antenna based system under correlated channel conditions.

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