AN FPGA IMPLEMENTATION OF ALAMOUTI'S TRANSMIT DIVERSITY
TECHNIQUE

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ABSTRACT

Wireless communications have grown tremendously over the last decade, wireless LAN and mobile telephones have been the main reasons for the growth. There is demand for ever faster wireless communications as this will allow for new applications such as wireless broadband Internet access. Multi-Antenna transmission schemes, using multiple antennas at the transmitter and/or receiver, and associated coding techniques have been proposed as a way to fulfill the demand for increased capacity and the performance of wireless communication systems. They are particularly attractive because they do not require any additional transmission bandwidth, and unlike traditional systems use multipath interference to their benefit. However, there are limits to growth, and the radio spectrum used for wireless communications is a finite resource. Therefore considerable effort has been invested in making more efficient use of it. Using the spectrum more efficiently caters for the ever increasing demand for faster communications since more bits per second can be transmitted using the same bandwidth. This project aims to present the Xilinx/Altera FPGA implementation of a multiple antenna wireless communications system based on Alamouti's transmit diversity scheme [1]. Alamouti's transmit diversity scheme is a space-time block code with support for two transmit antennas and an arbitrary number of receive antennas. The implementation demonstrates this space-time code in a baseband system with two transmit and just one antenna at the receiver with the encoding and decoding algorithms using Verilog Hardware Description Language (HDL), which is modeled to establish an end-to-end link over real wireless channels to form a complete multiple antenna wireless communications system.

ABSTRAK

Wayarles LAN dan telefon mudahalih adalah penyumbang utama yang menyebabkan sistem komunikasi wayales berkembang dengan pesatnya pada dekad yang lalu. Masih terdapat permintaan untuk sistem komunikasi wayarles yang laju, yang membenarkan aplikasi baru seperti wayarles capaian Internet jalur lebar. Skema penghantaran berbilang antenna menggunakan beberapa antenna pada penghantar dan penerima. Bagi memenuhi permintaan dalam peningkatan kapasiti dan prestasi sistem komunikasi wayarles, beberapa teknik pengekodan yang tidak memerlukan penambahan lebarjalur telah dicadangkan. Walaubagaimanapun, perkembangan ini mempunyai hadnya kerana spektrum radio yang digunakan untuk komunikasi wayarles ini adalah terhad. Oleh itu, usaha telah diambil untuk mempergunakan spektrum radio ini dengan lebih cekap. Ini akan memenuhi peningkatan permintaan untuk sistem komunikasi yang laju kerana lebih banyak bit /s dapat dihantar dengan menggunakan lebarjalur yang sama. Projek ini bertujuan untuk melaksanakan sistem komunikasi wayarles berbilang antena yang berasaskan teknik kepelbagaian penghantaran Alamouti [1] dengan menggunakan perkakasan Altera/Xilinx FPGA. Skema kepelbagaian penghantar Alamouti kod blok ruang-masa ini boleh menampung dua antena penghantar dan bilangan antena penerima yang sembarangan. Pelaksanaan teknik ini akan mendemonstrasikan kod blok ruang-masa dalam sistem jalurdasar yang menggunakan dua antena penghantar dan satu antena penerima yang masing-masing melakukan pengekodan dan penyahkodan algoritma menggunakan "*Verilog Hardware Description Language* (HDL)". Sistem ini dimodelkan untuk mengadakan suatu perhubungan hujung-ke-hujung menggunakan saluran wayarles untuk membentuk satu sistem komunikasi wayarles yang lengkap.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

In recent years the telecommunications industry has experienced phenomenal growth, particularly in the area of wireless communication. This growth has been fueled by the widespread popularity of mobile telephones and wireless computer networking. However, there are limits to growth, and the radio spectrum used for wireless communications is a finite resource. Therefore considerable effort has been invested in making more efficient use of it. Using the spectrum more efficiently caters for the ever increasing demand for faster communications since more bits per second can be transmitted using the same bandwidth.

A major research focus in this area has been the use of multiple antennas for transmitting and receiving instead of the traditional single antenna [1]. It has been proposed that using multiple transmit and receive antennas, and associated coding techniques could increase the performance of wireless communication systems [6] The diversity gain is responsible for the improvement in quality of communication link and can be obtained through the use of STC (Space Time Coding) [12] which spreads the transmitted symbols over the space and time dimensions.

The first excellent work in the space-time coding subject was presented by Alamouti, Siavash M. [1]. In it the transmission necessarily occurs through two antennas, with one or more antennas in the reception. An important characteristic of the Alamouti's scheme is its simplicity, in the codification and in the decodification, making of this as ideal candidate for real-world implementation. Alamouti's scheme already is consolidated in the scientific area and is used in the standards of the UMTS WCDMA of third generation [5]. Two transmit diversity scheme with OFDM, space-time OFDM (ST-OFDM) and space-frequency OFDM (SF-OFDM) are also based on the transmit diversity scheme proposed by Alamouti as described in [4].

It could also be argued that Alamouti's transmit diversity scheme was the first example of a space-time code which requires only linear processing at the receiver. Previous space-time coding schemes used trellis based processing [5]. While they provided substantial gains in a wireless communications system, these trellis- based coding schemes were much more complicated to implement than the scheme proposed by Alamouti. The simplest case of Alamouti's scheme utilizes two transmit antennas and one receive antenna. Alamouti included a generalization of his scheme to an arbitrary number of receive antenna [2].

1.2   Objectives

This project aims to present the Altera and Xilinx FPGA implementation of a multiple antenna wireless communications system based on Alamouti's transmit diversity scheme [1. The implementation demonstrates the space-time code in a system with two transmit and just one antenna at the receiver with the encoding and decoding algorithms, which establishes an end-to-end link over real wireless channels to form a complete multiple antenna wireless communications system with certain assumptions made. The design requires providing the RTL code (Verilog

'01) for the encoding and decoding algorithm. The design is then verified and debugged and finally implemented on Altera and Xilinx FPGAs using the Quartus II tool and ISE tool respectively.

1.3   Scope of project

At the initial stage, the project consists of two major parts which are the transmitter and receiver system. The design of the transmitter and receiver are based on the encoding and decoding algorithm of the S.M. Alamouti [1]. Verilog, Hardware Description Language (HDL) is used to design, model and verify the system. The design is implemented on both Altera and Xilinx FPGA boards. The implementation process involves the process of translating, mapping and place and routing the design onto the FPGA.

The general block diagram of Alamouti transmitter and receiver are shown in Figure 1.1 and Figure 1.2 respectively. However, this design does not include the complete flow of the transmission as shown in Figure 1.1 and Figure 1.2. The Alamouti transmitter and receiver design in this work excludes pulse shaping and upsampling and upconversion on the transmitter and the downconversion and downsampling, timing recovery and carrier recovery on the receiver.
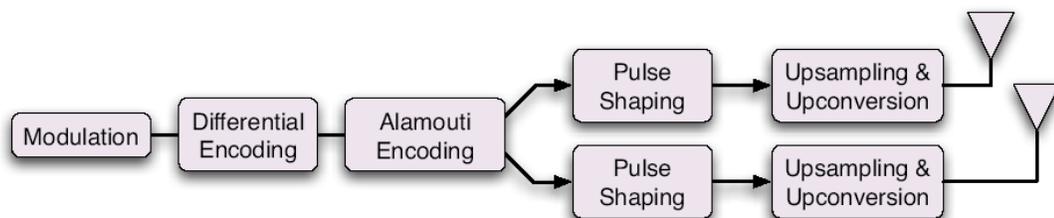
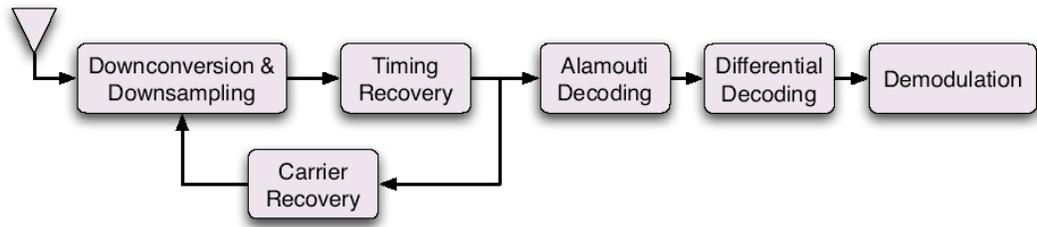Figure 1.1: General block diagram of Alamouti transmitter

Figure 1.2: General block diagram of Alamouti Receiver

Due to the absence of these parts, the signals cannot be transmitted from the transmitter to the receiver over real wireless channels. Therefore, to perform the transmission in order for the implementation onto the FPGA, signals form the Alamouti transmitter had been connected directly via cable to the Alamouti receiver. However, the behavior of these signals which are connected directly to the receiver needed to be modeled as if they had been through the real wireless channels. To fulfill this requirement, we have included another part in the design which is the channel modeling.

Therefore, the overall project consists of two major parts and an intermediate part which are the Alamouti transmitter, Alamouti receiver and the channel modeling respectively. Figure 1.3 and Figure 1.4 shows the design of Alamouti transmitter and receiver respectively. The Alamouti transmitter and receiver are made up of three circuits and two circuits respectively. The Alamouti transmitter consist of the serial-to-parallel converter, QPSK modulator and the Alamouti encoder and the Alamouti receiver consist of Alamouti decoder and QPSK demodulator. The behavior of each of these blocks's are explained in detail in Chapter 4.
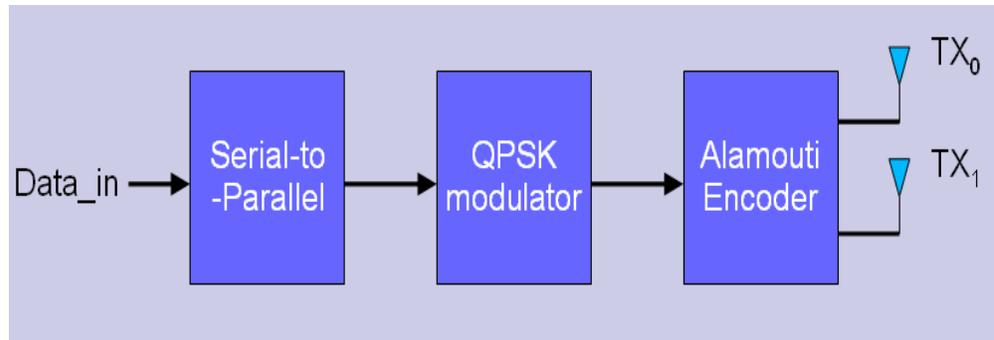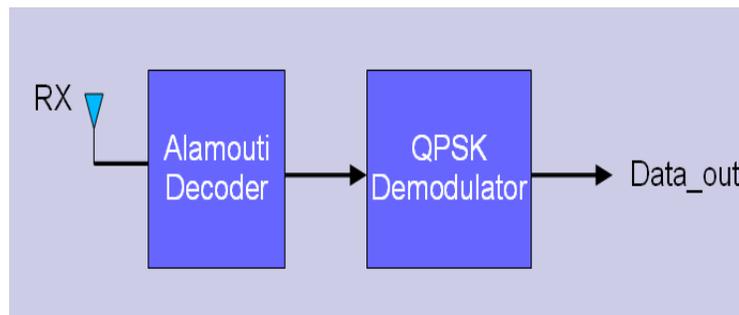
Figure 1.3: Alamouti Transmitter

Figure 1.4: Alamouti Receiver

There are several assumption made for the designed system. The first assumption is that the fading and inputs are constant for the duration of the encoding process, two consecutive symbols. Also, the input bits are modulated into symbols of real (Q) and imaginary (I) and these numbers are integers. The receiver is also assumed to have the knowledge of the channel experienced by the signal. Due to this, the design does not require a channel estimator and Maximum Likelihood (ML) part of design. And as mentioned earlier, in the design the transmitted signal is directly connected and the channel modeling modifies the transmitted signal to behave as it should as if the signal had been transmitted over real wireless environment before being received at the receiver. Also assume that there is no noise and interference present at the receiver.

The remainder of the thesis is organized as follows. Chapter 2 describes the overview and the literature of the Alamouti's transmit diversity technique. Chapter 3 describes the overview and the literature of an FPGA designs. Chapter 4 discusses the actual design of the in detail, part by part on the RTL and the implementation onto the FPGA. Chapter 5 discusses the obtained results of both implementation report of Altera/ Xilinx and concludes the project. Finally Chapter 6, the recommendations on what could be extended in terms of the design for the enhancement of the project in terms of design, implementation and the RTL code.

REFERENCES

1. S. M. Alamouti, "A simple transmit diversity technique for wireless communications," IEEE Journal on Select Areas in Communications, vol. 16, pp. 1451–1458, October 1998.

2. V. Tarokh, H. Jafarkhani, and A.R. Calderbank, "Spacetime block codes from orthogonal designs," IEEE Transactions on Information Theory, vol. 45, pp. 1456–1467, July 1999.

3. F. Harris andM. Rice, "Multirate digitla filters for symbol timing synchronization in software defined radios," IEEE Journal on Select Areas in Communications, vol. 19, pp. 2346–2357, December 2001.

4. C. Dick, F. Harris, and M. Rice, "Synchronization in software radios- carrier and timing recovery using FPGAs," in Proceedings of 2000 IEEE Symposium on Field-Programmable Custom Computing Machines, April 2000, pp. 195–204.

5. P. Murphy, F. Lou, and J. Patrick Frantz, "A hardware testbed for the implementation and evaluation ofMIMO algorithms," in Proceedings of the 2003 Conference on Mobile and Wireless Communications Networks, October 2003

6. Luiz Henrique Maia Junior, Rui ROdrigues Simoes Junior, "An FPGA Implementation of Alamouti's Transmit Diversity Technique Applied To An OFDM System," IEEE J.2006.

7.   G. J. Foschini, "Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas," Bell Labs. Tech. J., vol. 1, no. 2, pp. 41-59, 1996

8.   S. Alamouti, V. Tarkoh, and P. Poon, "Trellis coded modulation and transmit diversity," ICUPC, pp. 703-707, 1998.

9.   Ian Griffths. "FPGA Implementation of MIMO Wireless Communications System" B. Eng. Thesis. University of Newcastle, Australia; November 1, 2005.

10.   http://www.xilinx.com

11.   http://www.altera.com

12.   P. Gupta, W. Zhu, and M. Fitz, "Field test results for space- time coding," in Asilomar Conference on Signals, Systems, and Computers, Asilomar, CA, November 2003.

13.   N. Seshadri and J. H. Winters, "Two signaling schemes for improving the error performance of FDD transmission systems using transmitter antenna diversity," in Proc. 1993 IEEE Vehicular Technology Conf. (VTC 43rd), May 1993, pp. 508–511.

14.   A. Wittneben, "A new bandwidth efficient transmit antenna modulation diversity scheme for linear digital modulation," in Proc. 1993 IEEE International Conf. Communications (ICC'93), May 1993, pp. 1630–1634. in 1989 and 1991, respectively.