Implementation and Performance Evaluation of OFDM Transceiver

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Abstract— Orthogonal Frequency Division Multiplexing (OFDM) transmissions are emerging as important modulation technique because of its capacity of ensuring high level robustness against interference. The actual and next communication schemes tend to use OFDM systems in order to provide high baud rates and less inter symbol interference. Some examples are 802.11, 802.16, MC-CDMA, Digital Video Broadcasting among others. Trying to provide a solution to the new devices emerging, slow standard adoption, poor spectrum use, etc. Joe Mitola introduced the concept of “Software Defined Radio”, which involves exhaustive configurable digital signal processing like FFT, therefore FPGAs could support many of its operations. This work presents a FPGA design, validation and implementation of an “Orthogonal Frequency Division Multiplexing” (OFDM) modulator for IEEE 802.11a, also reports the resources requirements for the presented system. In this paper the design and implementation of OFDM system will be illustrated as well as a detailed simulation of the OFDM system using MATLAB-2013 program to study the effect of various design parameters on the system performance, also the design and simulation results for some standards of OFDM using MATLAB will be observed as a practical system examples that uses OFDM as a modulation technique.

Key words: QAM, SDR, FPGA, OFDM

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) could be tracked to 1950’s but it had become very popular at these days, allowing high speeds at wireless communications [1]. While OFDM has become the core of most 4G communication systems as fixed Wi-Fi system (IEEE802.11a standard), mobile Wi-Fi system (IEEE802.11b standard), fixed WiMAX system(IEEE802.16a standard), mobile WiMAX system (IEEE802.16e standard), and Long Term Evolution (LTE) system; it was essential to build this OFDM system on a suitable hard ware. A basic OFDM system consists of a QAM or PSK modulator/demodulator, a serial to parallel / parallel to serial converter, and an IFFT/FFT module. The iterative nature of the FFT and its computational order makes OFDM ideal for a dedicated architecture outside or parallel to the main processor. Using FPGA instead of an ASIC gives also flexibility for reconfiguration, which is a need for the Software Defined Radio (SDR) concept. The focus of this work is to validate the suitability of reconfigurable devices such as FPGAs to perform IF “Intermediate Frequency”processing to support SDR [2]. Unlike an Application- Specific Integrated Circuit (ASIC), FPGAs can be reprogrammed multiple times, even after deployment. The high speed, parallel architecture provides complete control over the degree of parallelism in the design, and arithmetic word lengths. This flexibility is a key advantage of FPGAs over traditional Digital Signal Processor (DSP) processors. Many recent high speed digital signal processing applications such as networking, video and image processing and communications are implemented by using FPGA [3]. This paper aims to give an idea of what is an OFDM system, its implementation and the analysis of the obtained results of the simulations testing. This OFDM system is able to support different M-QAM modulation schemes.

Present work is divided as follows: Section II presents the related work; section III presents a brief description of the Std. IEEE 802.11 and OFDM fundamentals; at section IV the block diagram, the explanation of each block as the system design are presented; section V is dedicated to results and finally at section VI conclusions are discussed.

II. RELATED WORK

Moisés Serra [4] shows the design of an OFDM transmitter as a part of an OFDM demonstrator Hiperlan/2 based, Ma. José Canet [5] shows implementation issues of a digital transmitter for an OFDM based WLAN systems and benchmarks some optimized VHDL area resultsagainst System Generator results, Canet’s work is focused on the solutions for the OFDM signal generation in baseband and in intermediate frequency (IF).

Chris Dick [6] emphasizes the suitability of high-level design tools when designing sophisticated systems, and the importance to design FPGA systems rather than ASIC to one day accomplish the SDR “Software Defined Radio” concept and gives a high-level overview of the FPGA implementation giving some deep to the synchronization, packet detection, preamble correlate channel estimation and equalization; that is mainly at the OFDM receiver. Ludovico de Souza et al. [7] present a FPGA implementation capable to support 802.11 wireless modems but just as a validating and prototyping stage for an ASIC. Joaquin Garcia, Rene Cumplido [8] focuses on the FPGA suitability to support IF processing for the Std. IEEE 802.11a and the resource area and timing requirements either for rapid prototyping or to take advantage of re-configurability in order to be able to support different standards. Y. Awad, L. H. Crockett and R. W. Stewart [9] investigate the efficient FPGA implementation of an OFDM transceiver design for the IEEE 802.20 physical layer. Paul Guanming Lin [10] demonstrates the concept and feasibility of an OFDM system, and investigates how its performance is changed by varying some of its major parameters. This objective is met by developing a MATLAB program to simulate a basic OFDM system. M. A. Mohamed [11] presents an FPGA technique to gain approach in the problem of OFDM system implementation.

A. The Standard IEEE 802.11:

Standard 802.11 [13] also known as ISO/IEC DIS 8802- 11 is part of a family of standards for local and metropolitan area networks Std IEEE 802. The standard IEEE 802.11 covers the Wireless LAN Medium Access Control and Physical Layer Specifications. 802.11a specifies OFDM as the multiplexing and modulation technique for the wireless LANs supporting this standard, which covers the physical and medium access specifications. Some of the specified aspects of the standard are IFFT/FFT of 64 points where 48 of the subcarriers are used to carrier data from BPSK, QPSK, 16- QAM or 64-QAM alphabet; four pilot signals are added to the sub-carriers, for phase tracking, then the symbol is zero padded to complete the 64 points after IFFT module 16 point cyclic prefix is added to have a complete OFDM symbol (80 points); the OFDM symbol's period is 4 µs, while an IFFT symbol duration is 3.2 µs, that is a rate of 4/5 which uses to be a health rate for OFDM systems [14]. In the following section given a brief description of OFDM which is the one employed by 802.11, but not limited to this standard.

B. B. OFDM Fundamentals:

OFDM is a special case of multi-carrier transmission, where a single data stream is transmitted over a number of lower rates sub-carriers. On classical frequency division multiplexing the total band is divided into N nonoverlapping frequency channels, while on OFDM the band is divided into a number of overlapping frequency channels [9] but with orthogonal frequencies, the consequence is a better use of the available spectrum. Those orthogonal frequencies could be achieved by the IFFT. As described at Std. IEEE 802.11a [5] the OFDM Physical layer (PHY) transmitter blocks are: FEC Coder, Interleaving/Mapping, IFFT, Guard Interval (Cyclic Prefix), In Phase and Quadrature Modulation (IF) and finally the RF modulation. Those blocks as specified by IEEE 802.11a are shown at Fig. 1.

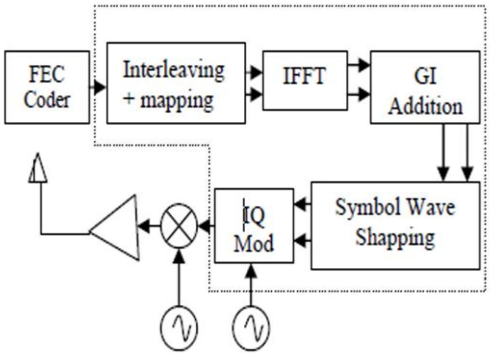

Fig. 1: 802.11a Transmitter Block Diagram for the OFDM PHY

III. OFDM OVERVIEW

OFDM is an attractive modulation scheme used in broadband wireless systems that encounter large delay spreads. OFDM avoids temporal equalization altogether, using a cyclic prefix technique with a small penalty in channel capacity. Where Line-of-Sight (LoS) cannot be achieved, there is likely to be significant multipath dispersion, which could limit the maximum data rate. Technologies like OFDM are probably best placed to overcome these, allowing nearly arbitrary data rates on dispersive channels. [12]. Each subcarrier can be modulated independently as shown in Fig.1. The spectra of the subcarriers overlap, but the subcarrier signals are mutually orthogonal as shown in Fig. 2 [12].

A. OFDM Advantages:

In general, OFDM systems have the following advantages: (i) efficient use of spectrum.; (ii) resistant to frequency selective fading; (iii) Eliminates ISI (Inter-Symbol Interference) and ICI (Inter-Carrier Interference); (iv) can recover lost symbols due to the frequency selectivity of channels; (v) channel equalization; (vi) computationally efficient [12].

B. OFDM Disadvantages:

OFDM systems have the following disadvantages: (i) High synchronism accuracy; (ii) Multipath propagation must be avoided in other orthogonality not be affected, and (iii) Large peak-to-mean power ratio due to the superposition of all subcarrier signals, this can become a distortion problem (Crest Factor) [12].

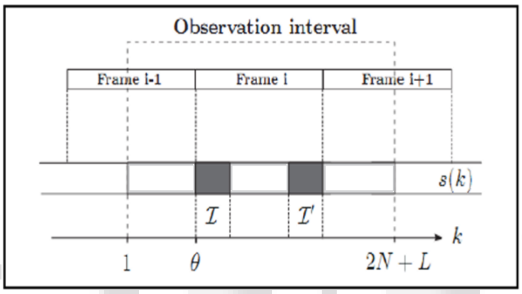

Fig.2: Structure of OFDM Signal With Cyclic Extended Frames

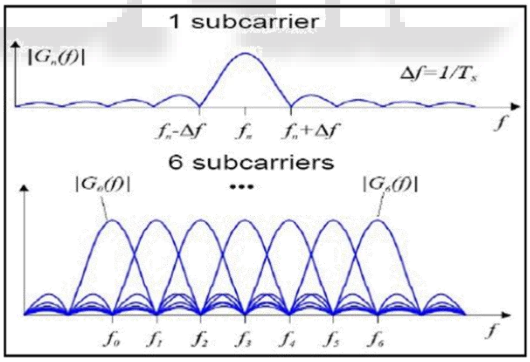

Fig. 3: OFDM Subcarriers in Frequency Domain

IV. OFDM TRANSCEIVER

The block diagram of an OFDM transceiver is shown in Fig. 4.

A. OFDM Transmitter:

OFDM splits a data-bearing radio signal into multiple smaller signal sets and modulates each onto a different subcarrier, transmitting them simultaneously at different frequencies, by using a number of parallel subcarriers spaced orthogonally as closely as possible in frequency without overlapping or interfering [1]. The main components of OFDM transmitter are shown in Fig.4 [9]. The randomizer is used as random bit generator. The first three blocks are used for data coding andinterleaving. The coded bits will be mapped by the constellation modulator using Gray codification, this way an + jbn values are obtained in the constellation of the modulator. The serial to parallel converter converts the data bits from the serial form to the parallel form. The Inverse Fast Fourier Transform (IFFT) transforms the signals from the frequency domain to the time domain; an IFFT converts a number of complex data points, of length that is power of 2, into the same number of points but in the time domain. The number of subcarriers determines how many sub-bands the available spectrum is split into [12, 15]. The Cyclic Prefix (CP) is a copy of the last N samples from the IFFT, which are placed at the beginning of the OFDM frame to overcome ISI problem. It is important to choose the minimum necessary CP to maximize the efficiency of the system [16].

B. *OFDM Receiver:*

The main blocks of OFDM receiver are observed in Fig.4. The received signal goes through the cyclic prefix removal and a serial-to-parallel converter [12]. After that, the signals are passed through an N-point fast Fourier transform to convert the signal to frequency domain. The output of the FFT is formed from the first M samples of the output. The demodulation can be made by DFT, or better, by FFT, that is it efficient implementation that can be used reducing the time of processing and the used hardware [17]. FFT calculates DFT with a great reduction in the amount of operations, leaving several existent redundancies in the direct calculation of DFT [17-19].

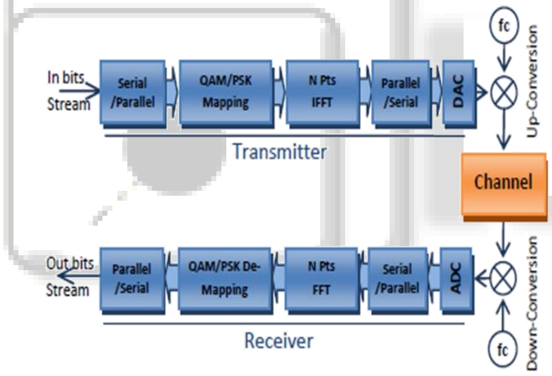

Fig. 4 OFDM Transceiver

This OFDM has 64 subcarriers modulated with 16-QAM scheme. The main blocks are:

1) *16-QAM Mapping:*

Each four bits generated by the pseudo random generator are mapped using the 16-QAM constellation. The “In-phase” and “Quadrature” signals are generated from the first and the last two bits respectively according to Table I. The four coding values (-3, -1, +1 and +3) are stored in a ROM memory block. The block diagram of 16-QAM mapping is demonstrated in Fig 4.

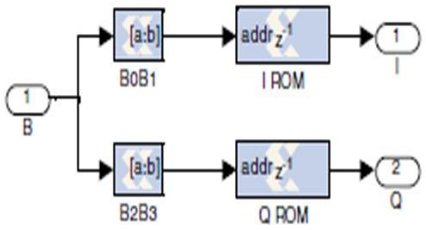

Fig. 5: 16-QAM Mapping

B_0B_1	In Phase (I)	B_2 B_3	Quadrature(Q)
00	-3	00	-3
01	-1	01	-1
10	1	10	1
11	3	11	3

Table. 1: Phase Coding

2) *Direct/Inverse Fast Fourier Transform:*

The FFT and IFFT are the most important blocks in the OFDM system and their performances have a big effecthe whole system; therefore, Xilinx Intellectual Property (IP) Core is used to perform a 64 Point (number of subcarriers employed) FFT or IFFT. This IP core is well optimised for a given device and can be configured to work in pipelined streaming I/O which means that the input data and output results are continuously fetched in and out respectively; Fig 4 shows an example using this IP core block.

3) *16-QAM De-Mapping:*

The De-Mapping is performed by assigning the received I-Q signals location to the nearest point in the I-Q constellation; therefore, I and Q signals are compared to a predefined threshold defined at the mid-way between two neighboring points. Fig 5 illustrates this principle.

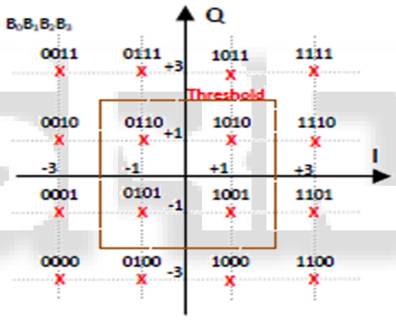

Fig.6: QPSK Modulated Signal

V. SOFTWARE SIMULATION

The input data stream is generated from a pseudo random generator implemented by a Linear Feedback Shift Register (LFSR) block. At the receiver, and in order to recover the subcarriers, the FFT should be applied on the received samples which must have the same order as the ones transmitted. To perform this synchronization the “Done” output of the IFFT block is set high upon the completion of the inverse Fourier transform. This will set the “Start” input of the FFT block to start receiving the transmitted samples.

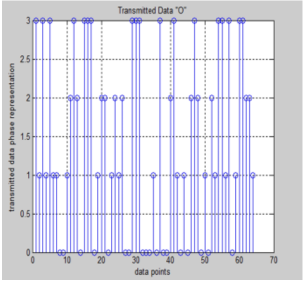

Fig .7: Transmitted Quantized Signal

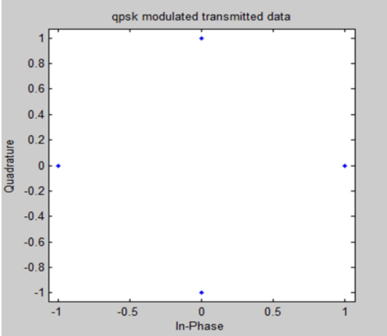

Fig. 8: QPSK Modulated Signal

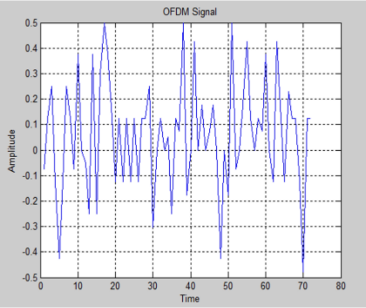

Fig. 9: Transmitted OFDM Signal

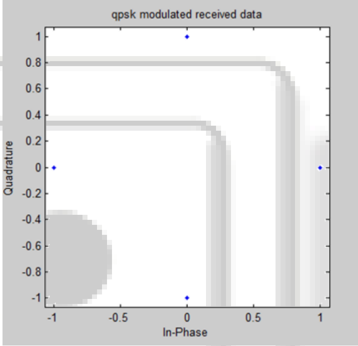

Fig. 10: Qpsk Modulated Received Signal

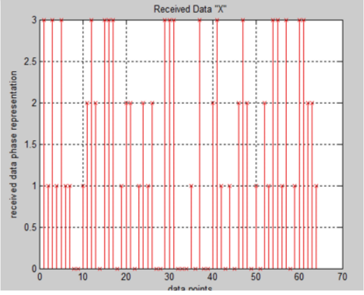

Fig. 11: Received Discrete Signal

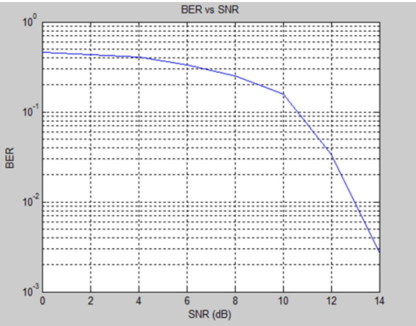

Fig. 12: BER vs SNR

The performance of the simulated OFDM has been evaluated over Additive White Gaussian Noise (AWGN) channel to estimate the BER for a given Signal to Noise ratio.

The simulation results of SNR vs BER are tabulated in

S.No.	SNR(dB)	BER
1.	0	0.35
2.	6	0.25
3.	10	0.15
4.	12	0.03
5.	14	0.0028
6.	>30	0

Table. 2: SNR vs BER

VI. CONCLUSION

The capability to design, simulate and implement an OFDM transceiver was achieved in this work by Exclusively MATLAB 2013. As probability of error must be reduced with increase in signal power and/or reduction in noise power the same is founded in MATLAB simulation that BER is decreased with increase in SNR in Fig:11. Fig:6 to Fig:10 are simulation results of OFDM without noise in MATLAB 2013.

In future work and in order to ensure the correct functionality of the OFDM system, frame synchronisation would need to be implemented. In addition, the OFDM transceiver will be further improved to allow a high order modulation scheme such as 256-QAM. Equalisation techniques will also be utilised to mitigate the effect of multipath fading, particularly over the 60 GHz wireless radio channel.

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