PERFORMANCE OF AN OFDM-BASED DVB-T SYSTEM AND ITS FPGA IMPLEMENTATION

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ABSTRACT

Orthogonal frequency division multiplexing (OFDM) is a new technique for data transmission. Conforming to the final draft of OFDM-based DVB-T (ETSI EN 300 744 V1.6.1), which is intended for digital terrestrial television broadcasting, a DVB-T baseband system is designed. The system performance is simulated in MATLAB using Simulink. Then it is implemented on Field Programmable Gate Array (FPGA) with the help of System Generator software. The result shows that OFDM is robust against multipath effect and convenient for implementation as well, thus owning a quite promising future.

KEY WORDS: OFDM, DVB-T, FPGA

I. INTRODUCTION

Wireless channels are inherently noisy. Due to frequency selective fading in frequency domain and multipath delay spread in time domain, to meet the demand for higher-speed data transmission, traditional single carrier modulation can no longer be sufficient. Orthogonal frequency division multiplexing (OFDM) splits a single wide-band carrier into a large number of orthogonal narrow-band subcarriers in parallel, which results in high tolerance toward multipath effect. OFDM has already been adopted in several technical standards, e.g., Asymmetrical Digital Subscriber Loop (ADSL), Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB) and IEEE 802.11 standards for wireless local area network (WLAN).

DVB is a suite of open technical standards for digital television, developed by the DVB Project [1]. Digital Video Broadcasting for terrestrial networks (DVB-T) is intended for digital terrestrial television (DTT) broadcasting and based on OFDM. DVB-T standardizes framing structure, channel coding and modulation [2]. Compared with other standards for DTT broadcasting, e.g., Advanced Television Systems Committee (ATSC) and Integrated Services Digital Broadcasting-Terrestrial (ISDB-T), DVB-T is the most widely adopted and deployed in the world, and has developed into the more advanced second generation system for terrestrial broadcasting (DVB-T2) [3].

As DVB-T is a typical OFDM system, after exploring fundamental principles concerning modulation process of OFDM, according to the final draft of DVB-T (ETSI EN 300 744 V1.6.1) [4], a baseband system is designed. The system is simulated in MATLAB using Simulink and implemented on Xilinx Spartan 3 Field Programmable Gate Array (FPGA) xc3s2000-5fg456 using System Generator software.

II. OFDM OVERVIEW

A. Principles of OFDM

The core of OFDM is to use many orthogonal narrow-band low-rate subcarriers for data transmission. In theory, OFDM maximizes the utilization of spectrum, attributed to the overlap between different subcarriers in frequency domain.

The modulation of OFDM is equivalent to inverse discrete Fourier transform (IDFT).

$$s(n) = s(nT) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} S(k) e^{j\frac{2\pi kn}{N}} \quad (0 \leq n \leq N-1) \tag{1}$$

While the demodulation of OFDM can be seen as discrete Fourier transform (DFT).

$$S(k) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} s(n) e^{-j\frac{2\pi kn}{N}} \quad (0 \leq k \leq N-1) \tag{2}$$

As IDFT and DFT can be realized using the existing time-efficient IFFT and FFT algorithm, the complexity of OFDM is greatly reduced.

During data transmission multipath effect will bring about ISI. To reduce the impact of it, certain length of cyclic prefix is inserted in front of every frame. As long as the length of cyclic prefix exceeds maximum of multipath delay spread, ISI can be avoided. And if different subcarriers keep orthogonal to each other, ICI can be eliminated as well.

The transmitter of a typical OFDM baseband system is made up of channel coding, serial-to-parallel conversion, signal modulation, IFFT, parallel-to-serial conversion, adding cyclic prefix and D/A conversion (DAC). While in receiver the opposite operation is conducted, i.e., A/D conversion, removing cyclic prefix, serial-to-parallel conversion, FFT, signal demodulation, parallel-to-serial conversion and channel decoding.

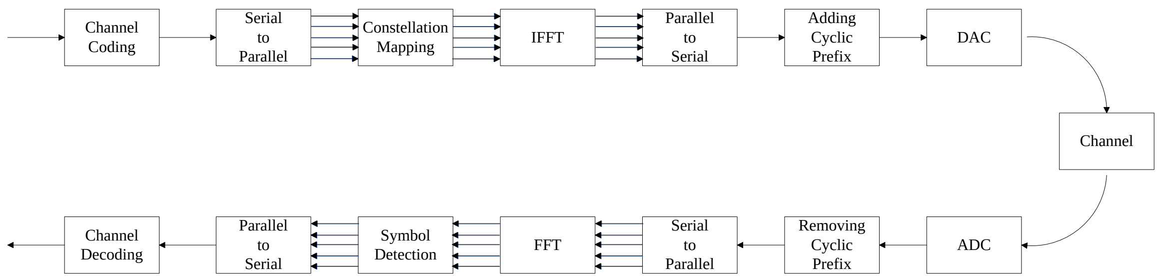

Figure 1. Typical OFDM baseband system

B. OFDM vs. Conventional FDM and CDMA

Compared with conventional frequency division multiplexing (FDM), as different subcarriers maintain orthogonal and overlapped, and no guard interval is needed in frequency domain, the spectrum utilization of OFDM is much more efficient. On the other hand, while OFDM modulation and demodulation can be realized using IFFT and FFT algorithm, for conventional FDM, a corresponding band-pass filter (BPF) is required for each frequency range, adding to the overall complexity.

Code division multiplexing access (CDMA) is the core technique of the present third generation telecommunication for mobile networking. Some research has already shown that OFDM performs better than CDMA in most conditions [5] [6].

III. DVB-T BASEBAND SYSTEM

A. DVB-T Standard

DVB-T is a DVB standard for digital terrestrial television (DTT) broadcasting, concerning the physical layer and data link layer of the distribution system. The core technique of DVB-T is OFDM, which presents high tolerance toward multipath effect. As during transmission the signal suffers from noise and multipath effect [8], DVB-T system adopts outer coding, outer interleaving, inner coding and inner interleaving to compensate for that.

According to the final draft of DVB-T (ETSI EN 300 744 V1.6.1) [4], there are two available transmission modes for DVB-T, hierarchical mode and non-hierarchical mode. The former allows two different transport streams delivered simultaneously, while for the latter only a single stream is permitted. After MUX adaptation and energy dispersal, the transport stream goes through concatenated Reed Solomon (RS) coding, i.e., RS(204,188). The RS coding can correct up to 8 random erroneous bytes in a received word of 204 bytes [4]. After that, the data is interleaved convolutionally and inner convolutional coding is required, along with puncturing. As when long bursts of errors exist, the performance of RS coding and Viterbi decoding deteriorates [9], bit and symbol interleaving, i.e., inner interleaving, which uniforms the errors, is set. After signal modulation and normalization, OFDM frames are formed by inserting scattered pilot cells, continual pilot carriers and transmission parameters signaling (TPS) carriers among the transmitted data. Then OFDM modulation is taken, with cyclic prefix inserted. Finally, after DAC is conducted, the baseband signal is converted into radio frequency and transmitted by front end.

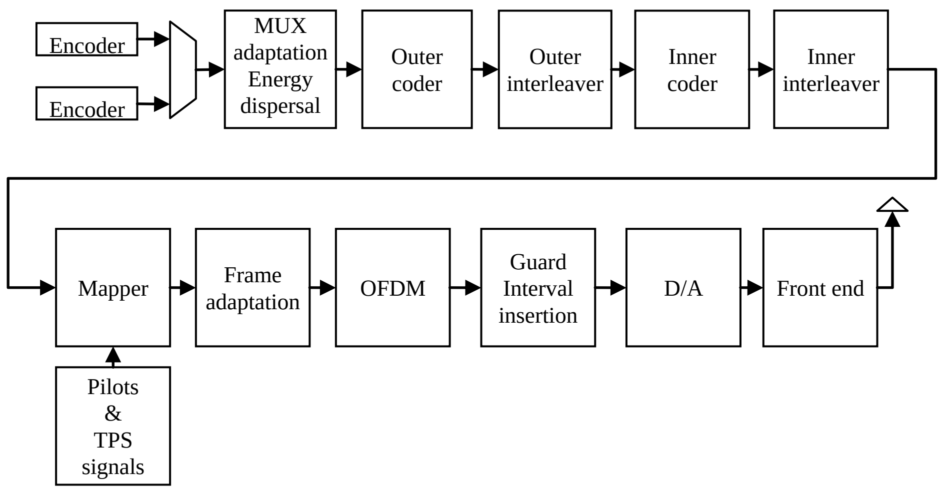

Figure 2. Functional block diagram of DVB-T system in non-hierarchical mode [4]

DVB-T does not regulate receiver. But usually the receiver just does the opposite operation, i.e., converting radio frequency signal to baseband by front end, synchronization, removing cyclic prefix, OFDM demodulation, equalization, signal demodulation, symbol and bit deinterleaving, Viterbi decoding, convolutional deinterleaving and RS decoding.

Table 1. Major parameters of DVB-T system [4]

Forward Error Correction	RS(204,188) Convolutional Coding(1/2, 2/3, 3/4, 5/6, 7/8)
Mapping Mode	QPSK，16-QAM，64-QAM
Guard Interval	1/4, 1/8, 1/16, 1/32
Transmission Mode	2K (2048 carriers), 8K (8192 carriers) Hierarchical, Non-hierarchical

B. Designed DVB-T Baseband System

Although some research has pointed out that wavelet-based OFDM outperforms Fourier-based OFDM in DVB-T system [10], as wavelet-based OFDM has not been put into practical use, the designed system still adopts IFFT and FFT algorithm for OFDM modulation and demodulation. It adopts code rate of 3/4, mapping pattern of 16-QAM, cyclic prefix length of 1/8 and 2K non-hierarchical mode.

Table 2. Parameters of designed DVB-T baseband system

Forward Error Correction	RS(204,188) Convolutional Coding(3/4)
Mapping Mode	16-QAM
Guard Interval	1/8
Transmission Mode	2K(2048 carriers), Non-hierarchical

In transmitter, the initial data goes through RS(204,188) coding, convolutional interleaving of size 12×17, convolutional coding of code rate 3/4, bit and symbol interleaving, 16-QAM mapping, 2048-point IFFT and adding cyclic prefix of length 1/8.

In receiver, the process of deciphering is composed of removing cyclic prefix of length 1/8, 2048-point FFT, equalizing, 16-QAM demodulation, symbol and bit deinterleaving, convolutional decoding using Viterbi algorithm, convolutional deinterleaving and RS decoding.

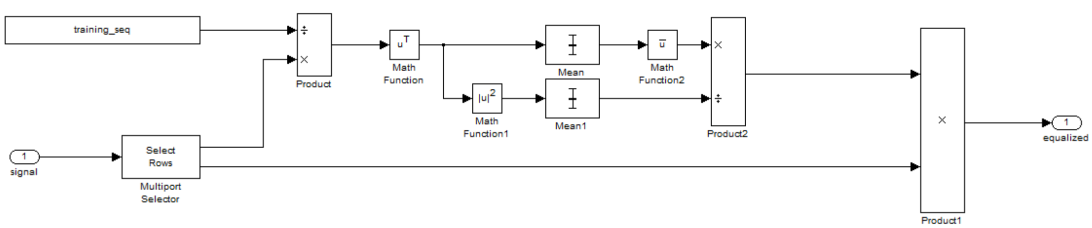

Figure 3. Illustration of the equalizer in receiver

IV. SIMULATION RESULTS

Consulting other simulation of DVB related systems [15] [16], the performance of designed DVB-T baseband system is evaluated under AWGN channel and multipath Rayleigh fading channel. The result is presented as bit error rate (BER) under different signal to noise ratio, which is shown as SNR.

The transmitter and receiver of designed DVB-T baseband system is constructed in Simulink and connected by AWGN channel and multipath Rayleigh fading channel. The multipath effect is assumed as two paths. The propagation delay and gain of the second path is set to 5×10^{-9}s and -3dB.

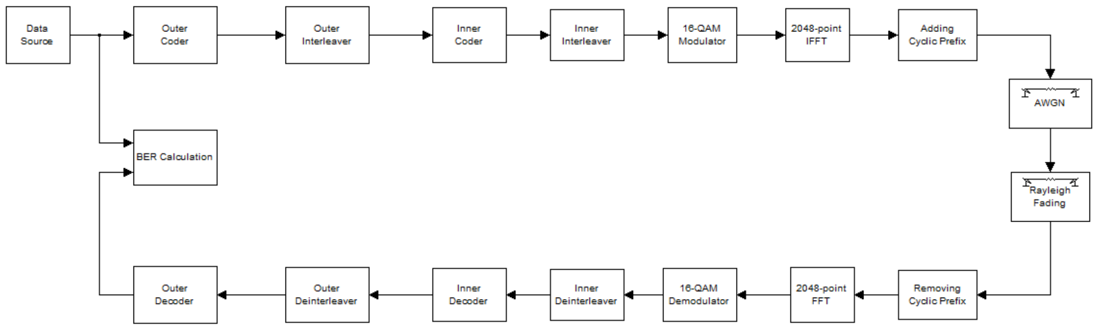

Figure 4. Designed DVB-T baseband system in Simulink

The result shows that the designed DVB-T baseband system owns a high tolerance toward multipath effect, especially when the propagation delay is below the length of inserted cyclic prefix.

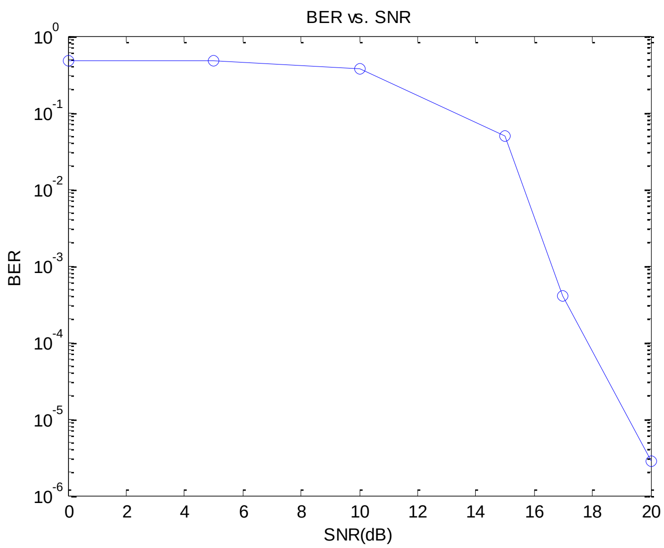

Figure 5. BER performance of designed DVB-T system under multipath channel

V. FPGA IMPLEMENTATION

System Generator software can automatically translate specific Simulink model into HDL for hardware implementation. Compared with traditional VHDL or Verilog programming, using System Generator is usually more time-efficient. And as the performance of each component in Xilinx blockset has been verified, the chance of error is comparatively low. Therefore System

Generator is used for FPGA implementation of designed DVB-T baseband system.

According to the design, transmitter includes RS encoder, convolutional interleaver, convolutional encoder, inner interleaver, 16-QAM modulator, 2048-point IFFT and adding cyclic prefix of length 1/8. In 16-QAM modulator, the mapping is achieved using block RAM; in 2048-point IFFT, pipelined streaming I/O is chosen. RS encoder, convolutional interleaver, convolutional encoder and IFFT are realized using intellectual property (IP) core.

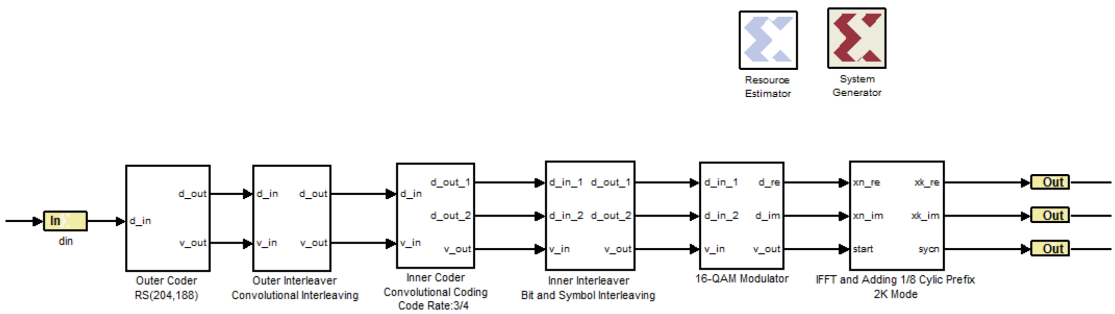

Figure 6. DVB-T baseband transmitter constructed by System Generator

Receiver is composed of removing cyclic prefix of length 1/8, 2048-point FFT, 16-QAM demodulator, symbol and bit deinterleaver, Viterbi decoder, convolutional deinterleaver, RS decoder. 2048-point FFT uses pipelined streaming I/O; 16-QAM demodulator is realized using block RAM. IP core is used when performing FFT, convolutional decoding, Viterbi decoding and convolutional deinterleaving.

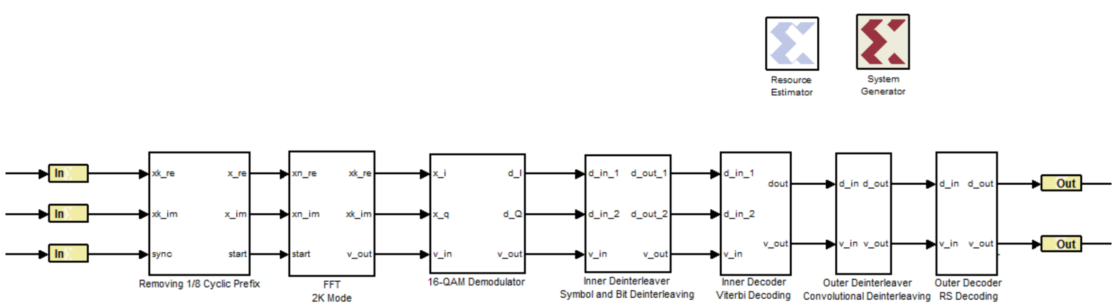

Figure 7. DVB-T baseband receiver constructed by System Generator

After building the system model from components of Xilinx blockset in Simulink, System Generator translates it into VHDL on Xilinx Spartan 3 FPGA xc3s2000-5fg456, generating the hardware description of designed DVB-T baseband system.

The device utilization summary shows that the transmitter and receiver of designed DVB-T baseband system can be implemented on a single middle-sized FPGA chip, thus verifying its capability of practical use.

Table 3. Device utilization summary of transmitter

Logic Utilization	Used	Available	Utilization
Number of Slice Flip Flops	9,589	40,960	23%
Number of 4 input LUTs	7,984	40,960	19%
Number of occupied Slices	6,945	20,480	33%
Total Number of 4 input LUTs	8,804	40,960	21%
Number of bonded IOBs	66	333	19%
Number of RAMB16s	16	40	40%
Number of MULT18X18s	28	40	70%
Number of BUFGMUXs	1	8	12%

Table 4. Device utilization summary of receiver

Logic Utilization	Used	Available	Utilization
Number of Slice Flip Flops	11,130	40,960	27%
Number of 4 input LUTs	11,066	40,960	27%
Number of occupied Slices	9,201	20,480	44%
Total Number of 4 input LUTs	12,094	40,960	29%
Number of bonded IOBs	27	333	8%
Number of RAMB16s	15	40	37%
Number of MULT18X18s	28	40	70%
Number of BUFGMUXs	1	8	12%

VI. CONCLUSION

The simulation of designed DVB-T baseband system shows that it can cope with multipath effect well. Although channel condition varies, with adequate length of cyclic prefix, the system performance can be reliable. By implementing the system on Xilinx Spartan 3 FPGA xc3s2000-5fg456, the feasibility of designed system is verified.

As DVB-T system is typically OFDM-based, the reliability and feasibility of designed DVB-T baseband system proves OFDM’s high tolerance toward multipath effect and its convenience for application.

Although OFDM still has several disadvantages, such as the high peak-to-average-power ratio (PAPR) problem of low power efficiency, and the vulnerability to frequency offset and phase noise, as it can guarantee both high-speed and high-quality for data transmission, it is a quite promising technique, especially under harsh channel conditions.

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