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Design and implementation of high throughput FPGA-based DVB-T system☆

Mehdi Ayat*, Hossein Hardani, Sattar Mirzakuchaki, Farzan Haddadi

Department of Electrical Engineering, Iran University of Science and Technology (IUST), Farjam, Tehran, Iran

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ABSTRACT

In this paper, an efficient implementation of high throughput Digital Video Broadcasting (DVB) system based on the Orthogonal Frequency Division Multiplexing (OFDM) modulation for terrestrial links is proposed. The proposed architecture uses an improved optimization methods to obtain high speed system. To verify the efficiency of this system a DVB-T simulator in MATLAB matched with European Telecommunications Standards Institute (ETSI) is used to investigate the hardware design performance. The joint simulation of Xilinx ISE and MATLAB was performed including information framing, channel coding, and modulation. Also, a systematic design procedure based on FPGA for the proposed DVB-T system is presented and the results are reported. Hardware implementation results demonstrate the effectiveness of the proposed system and show that there is a good match between fixed-point implementations and floating-point simulations, while the high-throughput architecture is achieved in hardware implementation using the speed optimization methods in the design.

1. Introduction

In recent years, the growing demand for multimedia services has promoted the development and expansion of broadcasting standards. However, due to limitations of the analog systems in the bandwidth efficiency, broadcast technology has moved to digital domain. By introduction of new standards such as Digital Video Broadcasting Terrestrial (DVB-T), DVB-Cable (DVB-C) and DVB-Handheld (DVB-H), new capabilities for multimedia transmission have been developed. One of the most widely used standards is DVB-T which is proposed by European Telecommunications Standards Institute (ETSI) for transmission of digital TV signal in 1997 [1]. DVB-T's advanced capabilities have caused the development of this standard in many other countries in addition to countries in Europe. This digital broadcast standard allows multi program broadcasting where 2 to 4 Standard Definition TV (SDTV) programs can be transmitted with an MPEG transport stream using coded Time Division Multiplexing (TDM) in a single 8 MHz channel [2]. DVB-T has brought a higher quality service to TV program and has reduced use of bandwidth. This standard relies on the Orthogonal Frequency Division Multiplexing (OFDM) modulation. Using OFDM will result in higher data rates, multipath avoidance in frequency selective channels and reduction in Inter-Symbol Interference (ISI).

Due to the data rates and power consumption, most DVB-T receivers are still stationary devices. But with rapid developments of technology, DVB-T standard has been also used in portable devices [3]. Current commercial DVB-T receivers are usually built from dedicated Application Specific Integrated Circuits (ASICs). However, ASICs are not flexible for upcoming

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* Corresponding author. Tel.: +00989362594932.
E-mail address: mehdiayat@iust.ac.ir (M. Ayat).

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evolved standards and they cannot be efficiently reused for different radio standards [4]. Along with the development in digital signal processing devices such as Field Programmable Gate Arrays (FPGAs) and Digital Signal Processors (DSPs), many attempts for transition from analog to digital domain have been done. The manifold advantages like the possession of large capacity, high accuracy, superior performance and high flexibility make it possible to realize a multimedia transmission standard on these devices. Different parts of DVB-T system have been studied in the literatures, such as the DVB-T receiver [5–8], DVB-T Fast Fourier Transform (FFT) Core [9] and symbol deinterleaver [10]. However, the performance of these systems has only been evaluated regarding the hardware receiver system. In some works [4, 6], the DVB-T architecture is implemented on DSP or Graphics Processing Unit (GPU) platform using parallel processing algorithms in order to improve the speed of the design. However, FPGAs are more suitable platforms for implementing high speed architectures due to their inherent parallel architecture. These reconfigurable architectures are most important candidate for implementing signal processing algorithms.

This paper presents a high data-rate digital multimedia transmission over terrestrial networks that focuses on information framing, channel coding, modulation, and hardware implementation issues. In order to achieve high throughput and efficiency of resources, different optimization methods are used in this paper. In Reed-Solomon (RS) coding, the Mastrovito algorithm is used to implement Galois Field multiplier which has parallel structure and higher speed compared to conventional multipliers. Additionally, according to a comparison made for different algorithms in [11], the Reformulated inverse-free Berlekamp–Massey (RiBM) algorithm is used in the RS decoder which leads to less critical path delay which in turn causes higher operating frequency compared to inversionless BM (iBM) and Euclidean methods. The folded structure has been used in outer interleaver implementation to reduce the required resources. According to [12], in the Viterbi decoder, the amount of required bandwidth for trace-back is less than register exchange method and consequently, using trace-back method can achieve higher speed in the hardware implementation. Hence, in this paper, trace-back method is applied for the path search in the Viterbi algorithm. Due to the importance of OFDM part in determining the maximum frequency of this work, efficient FFT algorithms are implemented in radix-2 and radix-4 modes. Design speed is improved by using radix-4 FFT and taking advantage of CORDIC algorithm for fast calculation of trigonometric functions. Finally, by using pipeline method, the critical path delay is reduced and operating frequency is increased. With these modifications the obtained system throughput is increased to 790 Mbps.

The rest of this paper is organized as follows: Section 2 presents a brief description of the DVB-T standard and the system structure. In Section 3, the system design is described and different parts of the system are discussed briefly. The simulation and experimental results and comparative analysis are discussed in Sections 4 and 5. Finally, conclusion and outlook are presented in Section 6.

2. DVB-T standard

Widespread digital broadcasting systems have significant advantages compared to their analog counterparts. Cable, satellite and ground antenna channels are three forms of digital television broadcasting systems abbreviated by DVB-C, DVB-S, and DVB-T, respectively. The main difference in these three types of broadcasting is the modulation method used in signal transmission. For transmitting TV programs by DVB-T standard, a transmitting antenna exhibits a wide beam and digital TVs can receive programs at a far distance from the transmitter antenna through the roof antenna. The DVB-T system is considered as the most widely used among all other DVB systems because of its compatibility with existing networks such as analog broadcasting systems [13]. In recent years, the DVB services have been extended to support mobile and stationary receivers. However, in portable devices, the multipath fading and the Doppler effects are the main concerns which cause signal distortion at the receiver. As a result, the performance degradation of the DVB-T systems will be troublesome when the mobile reception is considered. To solve this problem, channel coding methods are used. Channel coding protects the transmitted data against errors caused by channel and minimizes the undesirable effects of the transmission channel. In this approach, by adding redundant information to the original transmitted data, errors occurring in the channel are identified and corrected. The terrestrial network operator can choose one of two modes of operation [1]:

- 2K mode: suitable for single transmitter operations and small Single Frequency Networks (SFNs) with limited transmitter distances. It employs 1705 subcarriers over OFDM bandwidth of 7.61 MHz.
- 8K mode: suitable for both single transmitter operations and single frequency networks. It employs large number (6817) of subcarriers in the same bandwidth.

Table 1 presents the specifications of a DVB-T OFDM system in both 2K and 8K operational modes. The symbol duration for the former mode is 224 μs which is one-fourth of that occupied by the latter 8K-mode (896 μs). Both modes utilize the same modulation techniques (QPSK, 16-QAM and 64-QAM) and the same rate of convolutional encoders [14].

In the following section, the main parts of the DVB-T physical layer are introduced and discussed briefly. The details of the VLSI architectures are presented in the following subsections for each part, distinctly. Here, every part is implemented in general form and can be selected in order to achieve suitable order of modulation and code rate based on channel conditions. However, after discussing the main building blocks, some modifications in speed at different levels are introduced especially for critical parts which are more important and have larger path delay. It should be noted that in all levels of the design and for the interfaces between blocks, the suitable pipeline registers are added and in some parts, the retiming methods are used in order to achieve high throughput design.