Channel estimation evaluation in an ISDB-T system using GNU Radio

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Abstract — **This paper presents performance evaluations between different types of pilot-assisted channel estimations for the ISDB-T system. The GNU Radio open software tool was used for the implementation and performance measurements. Using an ISDB-T signal, the performance of each channel estimation was evaluated by using different multipath delays.**

Keywords: channel estimation, ISDB-T, SDR, GNU Radio.

I. INTRODUCTION

The Integrated Services Digital Broadcasting Terrestrial (ISDB-T) system was developed in Japan in 2003, and, currently, its modified version ISDB-T$_B$ is deployed in many countries in Latin America.

Due to the expansion of digital television, Single Frequency Network (SFN's) and gap fillers must be deployed to cover shadow areas. However, these deployments result in the arising of higher multipath delays. Then, it is necessary to improve the existing channel estimations in order to recover the received signal. As it can be verified in [1], [2], [3], there are different types of channel estimation, and each one has its own advantages.

This paper presents performance comparisons between different channel estimations. To achieve that, the GNU Radio open source software development toolkit [4] was used to implement C++ blocks that perform the desired signal processing. The GNU Radio Companion tool, a Graphical User Interface (GUI), enables the user to combine created blocks and already existing ones. This interface makes it easier for the user to understand the projects as a whole.

This paper is organized in five sections. In Section II, the ISDB-T system is presented as well as the Orthogonal Frequency Division Multiplex (OFDM) modulation. Section III contains the explanation of different pilot-assisted channel estimations. Section IV shows the obtained results. And finally, Section V, presents the conclusion of this paper.

II. ISDB-T SYSTEM

The ISDB-T system uses the Band Segmented Transmission-OFDM (BST-OFDM) modulation. It divides the spectrum in 13 segments for data transmission and 1 segment for upper and lower adjacent guard-band, thus improving the protection ratio of the signal. The 13 segments can be combined to create up to 3 different hierarchical layers that can be configured independently: A, B and C.

The ISDB-T system is able to transmit signals with bandwidths of 6, 7 or 8 MHz. As correction codes, ISDB-T uses shortened Reed Solomon (RS) (188, 204, 8) and a convolutional coder with a mother code rate of 1/2 (G1=171 oct; G2=133 oct) and puncture of 1/2, 2/3, 3/4, 5/6 or 7/8 [6].

The transmission of an ISDB-T signal is structured in frames, and each frame is composed of 204 OFDM symbols. Scattered Pilots (SP), Continual Pilots (CP), Transmission Multiplexing Configuration Control (TMCC) and Auxiliary Channel (AC) are inserted to guarantee channel estimation and synchronization [6].

In GNU Radio a flow-graph of an OFDM system with an ISDB-T signal, Fig. 1, was created to perform simulations with different channel estimations.

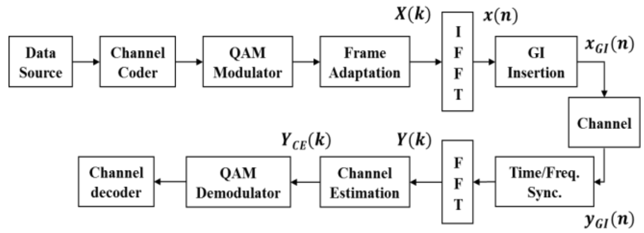

Fig. 1. OFDM system

After the channel coding, it is possible to modulate the signal in Quaternary Phase Shift Keying (QPSK), 16 or 64-Quadrature Amplitude Modulation (QAM). Then, an Inverse Discrete Fourier Transform (IDFT) must be applied to $X(k)$, resulting in (1). However, due to computational complexity, an Inverse Fast Fourier Transform (IFFT) is used in OFDM.

$$x(n) = IDFT\{X(k)\} = \frac{1}{N}\sum_{k=0}^{N-1} X(k)e^{j\frac{2\pi kn}{N}},\ 0 \leq n < N \qquad (1)$$

The number of useful carriers in an OFDM symbol in the ISDB-T$_B$ system can be set to 1405, 2809 or 5617 [5]. After the IFFT a Guard Interval (GI) is inserted, resulting in an ISDB-T signal that can be written as in (2),

$$x(n) = \begin{cases} x(N+n), n = -N_{GI}, N_{GI}+1, \dots, -1 \\ x(n), n = 0,1 \dots, N-1 \end{cases} \qquad (2)$$

where N_{GI} is the GI size, and N, the total number of carriers.

The GI size can be set to four different values. They are: 1/4, 1/8, 1/16 or 1/32 [5]. These values represent a fraction of the symbol's length.

The GI helps the system against multipath interference. This type of interference causes time delay spread over the OFDM symbols. If the time delay of an echo is bigger than the CP duration, it will land on the next symbol, resulting in Inter Symbol Interference (ISI).

An OFDM signal passing through a channel can be written as (3),

$$y_{GI}(n) = x_{GI}(n) \otimes h(n) + w(n) \qquad (3)$$

where $y_{GI}(n)$ is the received signal, $x_{GI}(n)$ is the transmitted signal, $w(n)$ is an Additive White Gaussian Noise (AWGN) noise and $h(n)$ is the channel impulse response. The symbol $\otimes$ denotes a linear convolution.

Before applying the FFT to the received signal, there must be a time and frequency synchronization stage [6]. Time synchronization detects where the symbol starts and where it ends, so the FFT window can process it correctly. To achieve that, the GI is used and a self-correlation is performed. The detected peak indicates the beginning of the symbol. If there is no knowledge about where the symbol starts, ISI will occur.

After time synchronization, a frequency synchronization is realized. It uses the self-correlation peak acquired value to calculate the fractional frequency error. This represents an error with a lower value than the space between the OFDM carriers. There is also an integer frequency error detection, also called carrier frequency offset (CFO). It is an integer multiple of the spacing value between OFDM carriers. However, this error detection is realized by the channel estimation module.

A FFT is applied to the synchronized signal, resulting in (4). Then, the signal is sent to the implemented channel estimation module.

$$Y(k) = X(k)H(k) + W(K) \tag{4}$$

A channel estimation is necessary for signal recovering after channel degradation. It equalizes the signal after obtaining the transfer function value of all carriers. The resulting signal can be written as in (5),

$$Y_{CE}(k) = Y(k)/H(k) \tag{5}$$

where $H(k)$ is the channel transfer function.

The channel estimation stage is also responsible for detecting integer frequency errors in the received signal. This stage performs a cross-correlation with a reference symbol. The resulting peak is the CFO. This value is sent back to the synchronization stage, so it can correct the signal with the complex exponential.

III. Pilot-Assisted Channel Estimation

The pilot-assisted channel estimation requires the frequency response of each received SP, represented by H_{SP} in (6) [7],

$$H_{SP}(k) = Y_{SP}(k)/X_{SP}(k) \tag{6}$$

where Y_{SP} and X_{SP} are the received and transmitted SP, respectively. The SP are in different positions in each symbol. In the ISDB-T there are four possible SP positions: 1, 4, 7, and 10. These values represent the starting position of the SP in each symbol. These positions change constantly from symbol to symbol, and each SP is 12 samples apart from each other [5]. The spaces in between must be interpolated both in time and frequency domain, called 2-dimensional (2D), or just in frequency domain.

There are several types of channel estimation, but in this paper 6 types were implemented and tested: Linear Piecewice (LP) and Cubic Spline (CS) [8]. Each one had 3 configurations: 1D (Freq.), 2D (Time and Freq.) and 2D (Freq. and Nearest in Time). The 2D with nearest interpolation in time uses the last symbol SP values so the frequency domain interpolation can be realized.

IV. Results

The tests were carried out using an ISDB-T signal with GI=1/8 and a 8K IFFT size. The GI time, T_{GI}, is 126 µs.

As a way of evaluating the implemented channel estimations, a channel with no AWGN noise and one multipath was used. Fig. 2 shows the needed echo to desired signal ratio (E/D) in dB at a specific delay for the Modulation Error Rate (MER) value to be greater than 19 dB, which is the approximated value of the the Signal to Noise Ratio (SNR) value in [9]. The MER values were measured at the channel estimation block output. E and D are, respectively, the echo and main signal power.

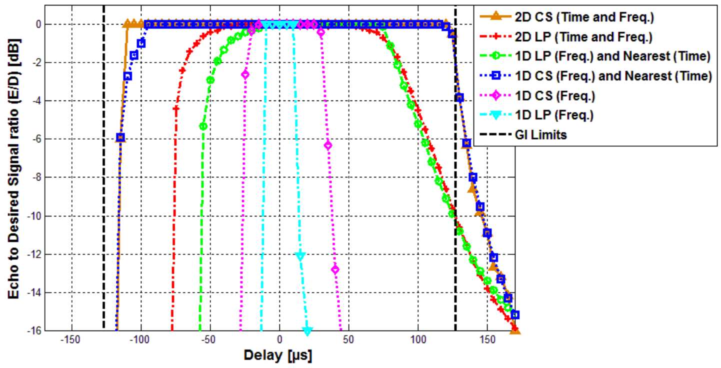

Fig. 2. Multipath performance

V. Conclusion

The 2D CS channel estimations clearly had a better performance than the 1D and 2D LP. Both 2D CS and 2D CS with Nearest interpolation had similar results. However, the 2D CS channel estimation had a slightly superior performance with pre-echo. 1D has proven to be a poor choice of channel estimation. With no time domain interpolation, the obtained values were not even near the GI limits.

Improved channel estimation techniques shall be able to achieve better results. Therefore, different channel estimation techniques must be implemented and tested in order to evaluate the performances.

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