An Improved Integer Frequency Offset Estimator using the P1 Symbol for OFDM System

Yong-An Jung and Young-Hwan You

Abstract—This paper suggests an improved integer frequency offset (IFO) estimation scheme using P1 symbol for orthogonal frequency division multiplexing (OFDM) based the second generation terrestrial digital video broadcasting (DVB-T2) system. Proposed IFO estimator is designed by a low-complexity blind IFO estimation scheme, which is implemented with complex additions. Also, we propose active carriers (ACs) selection scheme in order to prevent performance degradation in blind IFO estimation. The simulation results show that under the AWGN and TU6 channels, the proposed method has low complexity than conventional method and almost similar performance in comparison with the conventional method.

Keywords—OFDM, DVB-T2, P1 symbol, ACs, IFO.

I. Introduction

ORTHOGONAL frequency division multiplexing (OFDM) technique has been successfully applied to various digital broadcasting systems such as the second generation digital terrestrial transmission (DVB-T2), digital audio broadcasting (DAB), and digital radio mondiale (DRM) [1]-[3]. OFDM is commonly used for broadband wireless transmission because of its ability to prevent the multi-path channel problem. However, one of the main weakness of OFDM is its sensitivity to carrier frequency offset (CFO) caused by doppler shifts and/or oscillator instabilities. The CFO is normally decomposed into an integer frequency offset part and a fractional frequency offset part. If not properly compensated, the fractional frequency offset (FFO) causes the inter-carrier interference (ICI) on the fast fourier transform (FFT) output and the integer frequency offset (IFO) produces the cyclic shift of the output of the FFT in the receiver.

DVB-T2 adopts a specifically designed P1 symbol as the preamble of the DVB-T2 frame. Unlike conventional preamble, which are designed merely for supporting timing and frequency synchronization [4][5], the P1 symbol also supports the basic transmission parameter signalling (TPS), including the FFT size and single-input / single-output (SISO) and multiple-input / single-output (MISO) mode [1]. At the receiver, both TPS and CFO may be estimated by the P1 symbol. If the receiver can not accurately demodulated the TPS by CFO, it seriously degraded the performance of the system. Active carriers (ACs) of the P1 symbol are used for timing and frequency synchronization. 384 active carriers (ACs) are used as pilots, while other carriers are set to zero [6]. The boosting amount of the P1 symbol is a voltage ratio of $\sqrt{853/384}$, because the P1 symbol uses only 384 ACs out of 853 carriers

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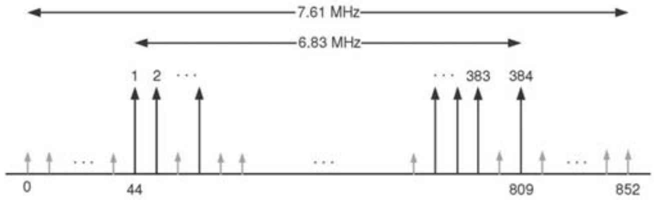

Fig. 1. The P1 symbol in the DVB-T2 system

available for a 1k OFDM symbol. The sub-carrier distribution of the P1 symbol is also illustrated in Fig. 1. The active carriers occupy roughly 6.83 MHz in the middle of the nominal 7.61 MHz bandwidth. Even a frequency shift of up to 500 kHz may be estimated, since most of the useful sub-carriers are still within the bandwidth. Therefore, the P1 symbol is robust to large CFOs. The pattern of ACs has been designed to have good auto-correlation properties for finding the IFO by studying the locations of the used carriers.

This paper proposes an improved IFO estimator using P1 symbol in frequency domain for DVB-T2 system. Firstly, an low-complexity IFO estimation without complex multiplications is proposed. Secondly, ACs selection scheme in order to prevent performance degradation of the blind IFO estimation is suggested. It is found by simulation that the DVB-T2 system is shown to contain sufficient information to synchronize a system.

The rest of the paper is organized as follows. The next section describes the system model. In Section III, estimation algorithms are presented. The simulation environment and detailed results are discussed in Section IV. Finally, conclusion are drawn in Section V.

II. System Model

We commence with the signal model of ODFM system and the focus our attention on the P1 symbol design of the DVB-T2 system. The transmitted time domain signal of an OFDM system can be represented as

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) e^{j2\pi kn/N}, \quad 0 \leq n < N, \qquad (1)$$

where $X(k)$ represents the modulated signals of the k-th subcarrier in frequency domain, N is the number of FFT points. To prevent the performance degradation due to multipath fading, guard intervals (GIs) are inserted before and after the P1 symbol in time domain.

After convolving with the channel impulse responses, the frequency offset is modeled as a phase distortion of the received data in time domain. The received signal $y(n)$ can be expressed as

$$y(n) = \Big(h(n) \otimes x(n)\Big) e^{j2\pi\Delta n/N} + w(n), \qquad (2)$$

where $h(n)$ is the channel impulse response in time domain, $\otimes$ means the convolution operator, Δ is the CFO normalized by carrier spacing and $w(n)$ is the contribution of the additive white Gaussian noise (AWGN) with mean zero. Generally, it is expedient that frequency offset Δ is divided into two parts, i.e., $\Delta = \Delta_i + \Delta_f$ with Δ_i=integer(Δ) and $\Delta_f \subset [-1/2, 1/2)$. In this paper, we assume that fractional part of frequency offset and timing offset are perfectly estimated and corrected before the estimation of the integer part. Then, the received signal of the OFDM symbol in frequency domain takes the form of

$$Y(k) = e^{j2\pi\Delta_i N_e/N} H(k - \Delta_i) X(k - \Delta_i) + W(k), \qquad (3)$$

where $X(k - \Delta_i)$ represents the Δ_i-th cyclic shifted version of $X(k)$ and $N_e = N + N_g$. $H(k)$ is the channel's frequency response, and $W(k)$ is a zero-mean complex Gaussian noise.

III. Proposed Estimation of Integer Frequency Offset

The IFO estimator typically used in the frequency-domain by exploiting two pilot blocks with differential encoding [7]. Also, only one pilot block is used in [8] which can be implemented with low complexity at the expense of the estimation performance, when compared to the former.

According to the DVB-T2 frame structure, a P1 symbol is used in DVB-T2 at the beginning of every T2-frame so that the receiver can promptly identify and decide the presence of DVB-T2 signal in the radio frequency channel. More importantly, P1 symbol is used to estimate the IFO. However, [7] method is not suitable for P1 symbol since the T2 frame comprises only one P1 symbol. Therefore, the IFO estimation scheme should be performed by the blind estimation using the P1 symbol for DVB-T2.

It is assumed that the timing error and FFO are perfectly corrected, the P1 symbol is extracted and transformed to the frequency-domain for IFO estimation and signalling detection. In the [9], the proposed a blind IFO estimation method which used one OFDM symbol. This conventional estimator uses an auto-correlation as follows

$$\hat{\Delta}_i = \underset{|r|\le M}{\arg\max} \left\{ \sum_{k\in S_p} Y(k+d) Y^*(k+d) \right\}, \qquad (4)$$

where d denotes a trial value of Δ_i, M denotes the largest expected value of $|d|$ depending on the frequency stability of the transmitter's and the receiver's oscillators, and $(\cdot)^*$ denotes the complex conjugation. S_p is the set of indices for used ACs.

The computational complexity of the estimation algorithms may be quantified in terms of the number of multiplications and additions required. The conventional method is calculated with complex multiplications and complex additions.

However, a proposed method can estimate the IFO with only complex additions because boosting power of all pilots is same in the P1 symbol. Then, the proposed IFO estimator can be expressed as

$$\hat{\Delta}_i = \underset{|d|\le M}{\arg\max} \left\{ \sum_{k\in S_p} |Y(k+d)| \right\}, \qquad (5)$$

This blind estimator has a drawback. The system has the severe performance degradation when the continuously distributed ACs are used as pilots.

To prevent performance degradation, we propose a set of the used pilots which has isolated ACs. The proposed set needs to satisfy the following condition

$$\hat{S}_p = \left\{ \begin{array}{l} k \| X(k-M)| + |X(k-M+1)| + \cdots \\ + |X(k-1)| \le \ T, \\ \ |X(k+1) + |X(k+2)| + \cdots \\ + |X(k+M)| \le \ T \end{array} \right\}, \ k \in S_p \qquad (6)$$

where the estimation range of the IFO is $|r| \le 4$, T is the boosting power of AC ($T = \sqrt{853/384}$), and the proposed set of used pilots is $\hat{S}_p$. The proposed set is decided by T because the selected pilots by (6) is isolated AC which don't have adjacent ACs.

TABLE I
Typical Urban profile (TU6)

Path No.	Delay(μs)	Average Power(dB)
1	0	-3
2	0.2	0
3	0.5	-2
4	1.6	-6
5	2.3	-8
6	5.0	-10

IV. Simulation Results

For convenience of analysis, we first assume that : The worst case is the set consisting of 3 consecutive ACs. The random case is the set consisting of randomly generated ACs. The proposed case is the set consisting of selected ACs by (6).

In order to verify the effectiveness of the proposed IFO estimator, we choose DBPSK modulation for transmission and take 1k mode with respectively 542 and 482 GI samples into account. The carrier frequency is 800MHz and the bandwidth is 7.61MHz. Two types of channel models were used for simulations: AWGN and Typical Urban (TU6) channel. It has been defined by COST 207 as a TU6 profile [10]. The profile parameters are given in table 1. Total number of used ACs is $\hat{S}_p = 32$ and the IFO is $\Delta_i = 2$.

Fig. 2 depicts the normalized correlation value of the proposed IFO estimator when $\hat{\Delta}_i = 0$. In the worst case scenario, the used pilot is the middle one of 3 consecutive ACs. From this figure, it is expected that the IFO estimation is failed in the worst case. However, it is observed that $\hat{\Delta}_i = 0$ is correctly estimated, when $\hat{S}_p$ is used.

Fig. 3 shows the probability of failure of the conventional and proposed IFO estimator, defined by Pr$\{\hat{\Delta}_i \ne \Delta_i\}$. From the simulation results, it can be observed proposed method

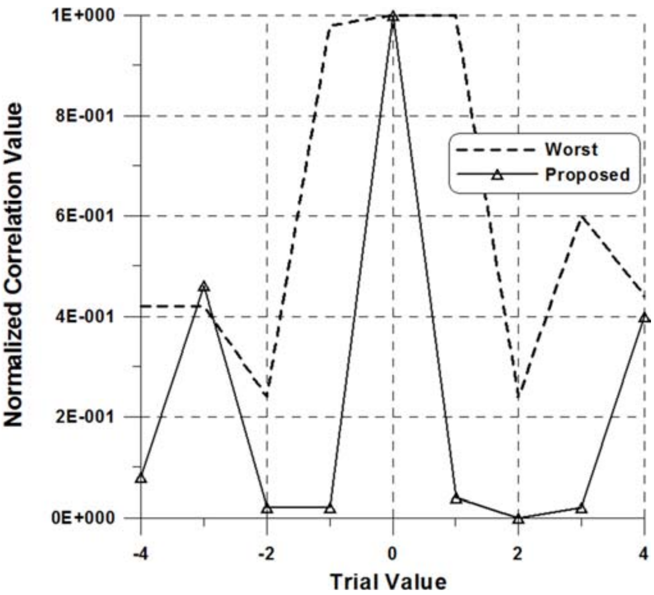

Fig. 2. Normalized correlation value of the proposed IFO estimator when $\hat{\Delta}_i = 0$

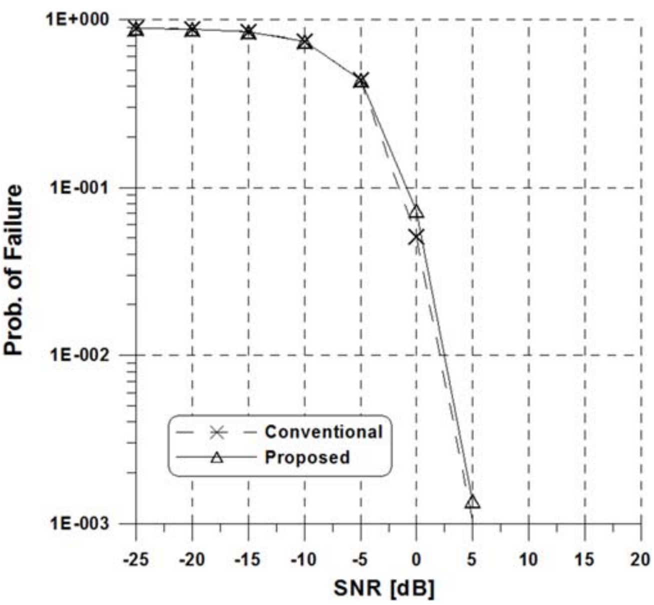

Fig. 3. Probability of failure of the conventional and proposed IFO estimator versus SNR

gives a same estimation performance when compared to the conventional method in AWGN channel.

Fig. 4 shows the probability of failure of the proposed IFO estimator in AWGN and TU6 channels, respectively. The performance of the proposed estimator is compared with that of other cases, and it is shown by simulation that the proposed case outperforms other cases than that of other cases. In result, the proposed method shows that the accuracy can be increased by using the proposed set.

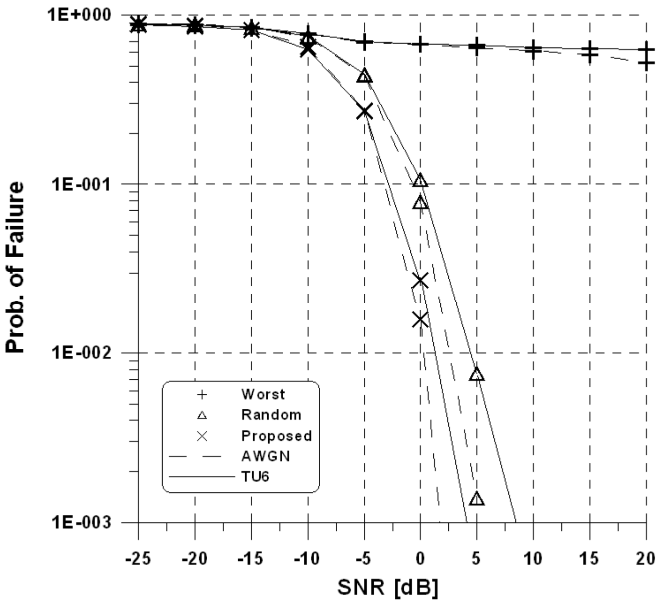

Fig. 4. Probability of failure of the proposed IFO estimator versus SNR: (1) dashed lines - AWGN (2) solid lines - TU6 channel model

V. Conclusion

This paper has proposed an improved IFO estimator using the P1 symbol for DVB-T2 system based on selecting isolated ACs scheme. The proposed IFO estimator with the same estimation performance was made to keep low computational cost and reduce the implementation complexity than conventional method. The simulation results show that under the AWGN and TU6 channels, the proposed method has low complexity than conventional method and almost similar performance in comparison with the conventional method.

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