Frequency Estimation for Non-pilot Mode of DVB-S2 System

Sooyeob Jung and Deock-Gil Oh

Abstract—**In this paper, we present a frequency estimation method for non-pilot mode of digital video broadcasting-satellite second generation (DVB-S2) system, which is based on a Rife and Boorstyn (R&B) algorithm. The proposed approach consists of the coarse and fine frequency estimation, which is performed by using a physical layer header (PLHEADER) instead of pilot symbols. In addition, it is required a modulation and code rate (MODCOD) decoding to obtain the PLHEADER. Compared with the other frequency estimation methods, the proposed method is very powerful in terms of both the estimation range and frequency offset sensitivity. The effectiveness of the proposed method is verified by simulation results.**

Index Terms—**Frequency estimation, non-pilot mode, digital video broadcasting-satellite second generation (DVB-S2), Rife and Boorstyn (R&B)**

I. INTRODUCTION

DUE to the rapid increase of high definition television (HDTV) and introduction of three dimension television (3DTV), the satellite broadcasting service has received considerable attention over the last few years. According to this trend, the digital video broadcasting-satellite second generation (DVB-S2) system has been adopted as the international telecommunication union-radio communication (ITU-R) and European telecommunications standards institute (ETSI) standard a couple of years ago [1]. In the pilot mode of DVB-S2 system, a certain amount of pilot symbols, which help the demodulation processes such as the frequency and phase estimation, are interleaved with the data streams. It provides both the simple signal processing and good performance. Therefore, the demodulation processes using pilot symbols are generally illustrated in many literatures [2]-[4], whereas these processes for non-pilot mode are rarely mentioned. However, since all requirements of the DVB-S2 standard should be supported in non-pilot mode, the demodulation processes for non-pilot mode should be studied more than ever.

In this paper, we focus especially on a frequency estimation method, which is one of the demodulation processes, in non-pilot mode. The proposed method is divided into the coarse and fine frequency estimation, which is based on a Rife and Boorstyn (R&B) algorithm [5]. This algorithm using the fast Fourier transform (FFT) operation has the advantage in terms of both the estimation range and frequency offset sensitivity. Also, it is useful in real implementation environment because the FFT [11] guarantees high performance as well as the simplicity. In the non-pilot mode, the proposed approach is realized by using a physical layer header (PLHEADER) instead of pilot symbols, because there is no pilot symbols. Additionally, a modulation and code rate (MODCOD) decoding is performed to obtain the PLHEADER. Simulation results demonstrate that the proposed frequency estimation method has the broad estimation range and low frequency offset sensitivity compared with other algorithms such as Luise and Reggiannini (L&R) [6], Fits [7], and Mengali and Morelli (M&M) [8].

The rest of this paper is organized as follows. The signal model is addressed in Section II. Section III presents the proposed frequency estimation. In Section IV, the effectiveness of the proposed approach is demonstrated with simulation results. The conclusion is made in Section V.

Notation: $\overline{(\cdot)}$ denotes the complex conjugate operation.

II. SIGNAL MODEL

In DVB-S2 system, the physical layer frame (PLFRAME) structure is constructed as shown in Fig. 1 [1]. However, since this paper assumes the non-pilot mode, the pilot symbols between data symbols are eliminated. Therefore, the PLHEADER, which is composed of 26 symbols of the start of frame (SOF) and 64 symbols of the physical layer signaling code (PLSC), instead of pilot symbols is used for the frequency estimation, because the SOF is already known and PLSC is simply obtained through the MODCOD decoding.

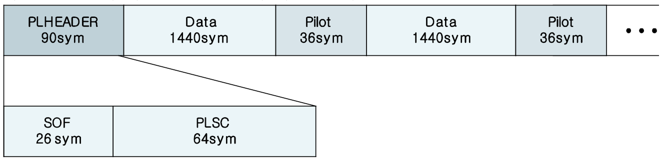

Fig. 1. PLFRAME structure in DVB-S2 system

In this system, the received PLHEADER signal can be expressed as

$$x(k) = c(k)\, e^{j(2\pi k \Delta f T + \theta)} + n(k), \tag{1}$$

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where $k = 0, \cdots, 89$ are timing indices, $c(k)$ is the $\pi/2$ BPSK symbol having unit-amplitude, Δf is the carrier frequency offset to be estimated, T is the symbol period, θ is the carrier phase, and $n(k)$ is additive white Gaussian noise with zero mean and variance σ_n^2. If a data-aided (DA) approach is adopted, the data ambiguity is easily removed by

$$z(k) = \overline{c(k)}x(k) = e^{j(2\pi k\Delta fT+\theta)} + n'(k), \qquad (2)$$

where $\overline{c(k)}c(k) = 1$ and $n'(k) = \overline{c(k)}n(k)$ is still additive white Gaussian noise with zero mean and variance σ_n^2. The DA algorithm is normally employed to attain good performance with short preambles. This signal model can be used to estimate the frequency offset Δf in the next section.

III. FREQUENCY ESTIMATION

The frequency estimation in DVB-S2 system is generally divided into the coarse and fine frequency estimation [2]-[4]. This paper also follows this strategy. The coarse and fine frequency offset is estimated by using 26 symbols of the SOF and 90 symbols of the PLHEADER, respectively. Additionally, the MODCOD decoding is performed to obtain the PLSC. And then, the PLHEADER is composed of the SOF of known data and PLSC of decoded data.

In this paper, both the coarse and fine frequency estimation are based on the R&B algorithm [5]. This algorithm has advantage in terms of the estimation range and frequency offset sensitivity compared with the other frequency estimation algorithms. In particular, the estimation range is the relative frequency offset that can be estimated and the frequency offset sensitivity addresses the accuracy degradation as a function of the initial frequency offset.

To show the frequency estimation, we need to introduce the R&B algorithm with the maximum likelihood (ML) operation:

$$\Delta\hat{f} = \arg\left\{\max_{f}\left[\left|Z(f)\right|\right]\right\}, \qquad (3)$$

where $Z(f)$ is the FFT operation applied to $z(k)$. The FFT operation is given by

$$Z(f) = \frac{1}{L_0}\sum_{k=0}^{L_0-1} z(k)e^{-j2\pi kfT}, \qquad (4)$$

where L_0 means the observation length in symbol intervals or FFT size. As the strength of this algorithm, the normalized frequency estimation range is $\pm 1/2$. Therefore, the R&B algorithm can cover the initial max frequency uncertainty, which represents 20 % of the symbol rate, in DVB-S2 system [2], [3]. Note that the R&B algorithm has the trade-off between the precision and complexity. Therefore, as the FFT size L_0 related to resolution increases, the estimation becomes more precise. Also, the proposed method has an advantage in real implementation environment because the FFT guarantees high performance as well as the simplicity.

A. Coarse Frequency Estimation

The coarse frequency estimation is performed by using 26 symbols of the SOF, which is known data. After the DA operation (2), the received SOF signal can be expressed as

$$z(k) = \overline{\mathrm{SOF}(k)}x(k) \qquad (5)$$

for $k = 0, \cdots, 25$, where $\mathrm{SOF}(k)$ is the known SOF in PLHEADER. In order to enhance the frequency resolution, zero-padding [9] by L_0 is additionally performed as

$$z'(k) = \begin{cases} z(k), & 0 \le k \le 25 \\ 0, & 26 \le k \le L_0 - 1 \end{cases}. \qquad (6)$$

After the DA and zero-padding operation, the coarse frequency estimation using R&B algorithm (3) is finally performed as

$$\Delta\hat{f}_{\text{coarse}} = \arg\left\{\max_{f}\left[\left|Z'(f)\right|\right]\right\}, \qquad (7)$$

where $Z'(f)$ is the FFT operation applied to $z'(k)$ as (4). If the estimated coarse frequency offset $\Delta\hat{f}_{\text{coarse}}$ is under the stable section, it can be utilized in the frequency recovery. Otherwise, the coarse frequency estimation should be restarted.

B. MODCOD Decoding

After the coarse frequency estimation, the PLHEADER is required to estimate the fine frequency offset. Therefore, the MODCOD decoding is obligatorily performed to obtain 64 symbols of the PLSC of unknown data. And then, the PLHEADER consists of the SOF of known data and PLSC of decoded data.

The composition of 64 symbols of the PLSC is illustrated in [1]. Firstly, the MODCOD bits $b_1, \cdots, b_5$ and one of TYPE bits b_6 are encoded by the $(32,6)$ Reed-Muller code. The result bits are expressed as $y_1, \cdots, y_{32}$. And then, by the exclusive-OR (XOR) with the rest TYPE bit b_7 and one bit delay operation, 64 bits of the PLSC are given by

$$\left(y_1, y_1 \otimes b_7, y_2, y_2 \otimes b_7, \cdots, y_{32} \otimes b_7\right)$$
$$\begin{cases} b_7 = 0 \rightarrow \left(y_1, y_1, y_2, y_2, \cdots, y_{32}, y_{32}\right) \\ b_7 = 1 \rightarrow \left(y_1, -y_1, y_2, -y_2, \cdots, y_{32}, -y_{32}\right) \end{cases}. \qquad (8)$$

Finally, 64 symbols of the PLSC are made by $\pi/2$ BPSK modulation.

The MODCOD decoding is performed by applying inversely the operation used for composition of the PLSC. Firstly, the TYPE bit b_7 is obtained by the complication operation between the even-th and odd-th symbols as

$$Z = y_1 \times \left(y_1 \otimes b_7\right) + y_2 \times \left(y_2 \otimes b_7\right) + \cdots + y_{32} \times \left(y_{32} \otimes b_7\right)$$
$$\begin{cases} Z < 0 \rightarrow b_7 = 1 \\ Z > 0 \rightarrow b_7 = 0 \end{cases}. \qquad (9)$$

To obtain the MODCOD and TYPE bits $b_1, \cdots, b_6$, we organize the $2^6 = 64$ candidates with 32 bits, which are made by the complication operation between the $b_1, \cdots, b_6$ bits and $(32,6)$ Reed-Muller code. And then, the $b_1, \cdots, b_6$ bits can be determined by ML operation with these candidates. Finally, the PLSC 64 symbols are obtained by the estimated $b_1, \cdots, b_7$ bits. And, the PLHEADER is made by summing the SOF and PLSC.

C. *Fine Frequency Estimation*

By using 90 symbols of the PLHEADER obtained in the previous subsection, the fine frequency estimation is performed like the coarse frequency estimation. The DA and zero-padding operation can be expressed, respectively, as

$$z(k) = \overline{\mathrm{PLHEADER}(k)} x(k) \tag{10}$$

for $k = 0, \cdots, 89$ and

$$z'(k) = \begin{cases} z(k), & 0 \le k \le 89 \\ 0, & 90 \le k \le L_0 - 1 \end{cases}, \tag{11}$$

where $\mathrm{PLHEADER}(k)$ is the PLHEADER estimated by the MODCOD decoding. And the fine frequency estimation has the high precision by selecting the longer L_0 than that used in the coarse frequency estimation. Finally, the fine frequency offset $\Delta \hat{f}_{\mathrm{fine}}$ is estimated by employing R&B algorithm (3). If the estimated fine frequency offset $\Delta \hat{f}_{\mathrm{fine}}$ is under the stable section, it can be utilized in the frequency recovery.

IV. SIMULATION RESULTS

In this section, the effectiveness of proposed frequency estimation method is demonstrated by the comparison with the other methods with respect to the normalized frequency estimation range and frequency offset sensitivity. And in order to show the property of several frequency estimation methods, the most essential aspects are summarized in Table I [9].

TABLE I
COMPARISON OF FREQUENCY ESTIMATION METHODS

Alg.	Accuracy	Freq. offset sensitivity	Normalized freq. estimation range	Complexity
Proposed method	High	Low	$\pm 1/2$	High
L&R	High	High	$\pm 1/L$	Low/ Medium
Fits	High	High	$\pm 1/(2L)$	Low/ Medium
M&M	High	Medium	$\pm 1/2$	Medium

In particular, the accuracy stands for the closeness to the modified Cramer-Rao bound (MCRB):

$$\mathrm{MCRB}(\Delta f) = \frac{3}{2\pi^2 N^3 T^2 E_s/N_0}, \tag{12}$$

where N is the symbol length. Table I shows that all methods provide the high accuracy and the proposed one of all methods has the highest complexity. However, the proposed method shows good performance in respect to the normalized frequency estimation range and frequency offset sensitivity. These points are demonstrated by simulation results.

Fig. 2-3 illustrates the normalized frequency offset variance of the proposed, L&R, Fits, and M&M methods with different signal-to-noise ratio (SNR) in various frequency offset environments. Assume that $N = 26$, $L = N/2 = 13$, $L_0 = 2048$. L is a design parameter used in the L&R, Fits, and M&M algorithm. As shown in Fig. 2, all of these algorithms are close to curve of MCRB in a low normalized frequency offset $\Delta fT = 0.01$. However, as the normalized frequency offset increases, the proposed method maintains

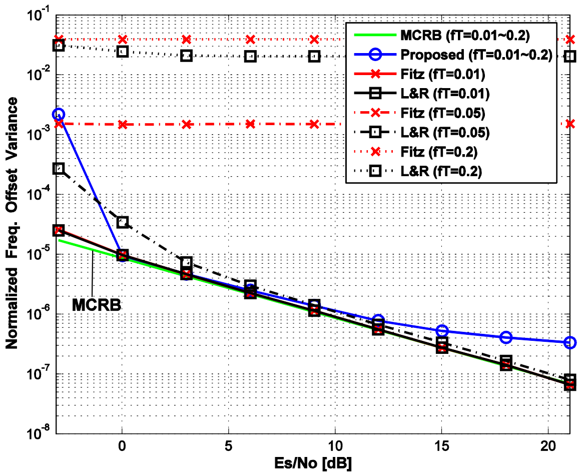

Fig. 2. Comparison with the normalized frequency estimation range of the proposed, Fits, and L&R methods in coarse frequency estimation

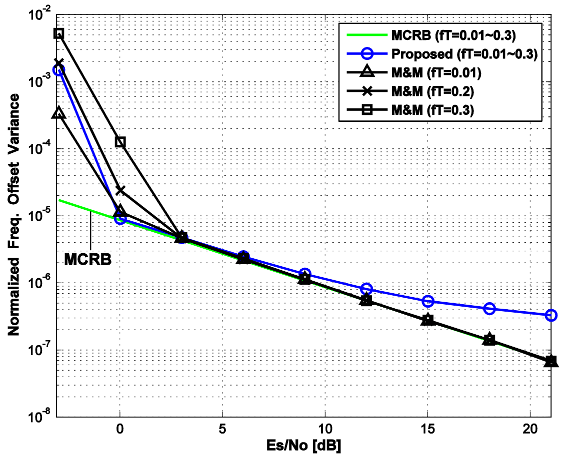

Fig. 3. Comparison with the frequency offset sensitivity of the proposed and M&M methods in coarse frequency estimation

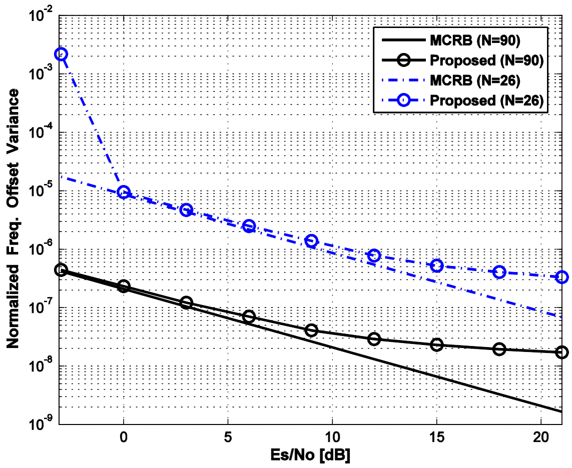

Fig. 4. Comparison with the accuracy in the coarse and fine frequency estimation

the curve whereas the L&R and Fits far away from the curve of MCRB. This result presents that the proposed method has the broad estimation range. On the other hand, the Fits of these algorithms has the narrowest estimation range.

Fig. 3 shows the comparison with the frequency offset sensitivity of the proposed and M&M methods in coarse frequency estimation. As the normalized frequency offset increases, the proposed method maintains the curve whereas the M&M shows the degradation of accuracy at low SNR. This result presents that the proposed method has the low frequency offset sensitivity.

In Fig. 4, it shows the comparison with the accuracy in the coarse and fine frequency estimation. Assume that $\Delta fT = 0.01$, $L_0 = 2048$ for coarse frequency estimation, $L_0 = 2048 \times 4$ for fine frequency estimation. The MCRB and proposed method using $N = 90$ outperforms that using $N = 26$. Note that the proposed method using $N = 90$ is closer to MCRB curve than that using $N = 26$, especially in a low SNR. It means that many symbols used the frequency estimation guarantee the good performance.

V. CONCLUSION

In this paper, we have studied the frequency estimation method, which is the core part of the receiver in satellite communication, especially for non-pilot mode of DVB-S2 system. The proposed approach is divided into the coarse and fine frequency estimation, which is based on the R&B algorithm. Additionally, the MODCOD decoding is performed to obtain the PLHEADER. The proposed method has advantage in terms of the estimation range and frequency offset sensitivity compared with the other methods and its validity is demonstrated by simulation results. Finally, we can derive the practical technique to satisfy the DVB-S2 standard and can be implemented in real environment.

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