The Frequency Offset Estimation Algorithm for DBO-CSS

Seung-Han Baik, Sang-Hun Yoon, Jong-Wha chong
Hanyang University, IT build 702, Haengdang-Dong, Sungdong-Gu, Seoul 151.724, Korea
Tel: +82-2-2220-0558, Fax: +82-2-2293-2929
back100sh@hotmail.com, shyoon11@hanyang.ac.kr, jchong@hanyang.ac.kr

Abstract **– In this paper, we propose a new frequency offset estimation algorithm for DBO-CSS which is a standard for wireless personal area network (WPAN). In DBO-CSS, there can be several integer multiples of 2π in the phase rotation caused by the frequency offset because of the long time difference between the samples of differential relation and the high permissible frequency offset of the crystal oscillators between the transmitter and the receiver. In this paper, we propose an estimation algorithm by using the relationships of each sub-chirp signals to find the integer part without phase ambiguity.**

Keywords **- DBO-CSS, chirp, frequency offset.**

I. INTRODUCTION

IEEE 802.15.4a working group selects both techniques of Impulse Radio UWB (unlicensed UWB spectrum) and DBO-CSS (2.5GHz unlicensed spectrum, [3]) as a standard.

There are many papers to estimate frequency offset. Schmidle and Cox [1], Moose [2] used frequency domain signal after FFT had been taken to estimate frequency offset. These algorithms are useful for the systems which need FFT step such as OFDM, but these algorithms are unsuitable for the systems processed in time domain like DBO-CSS that doesn’t need FFT step. Most of papers to estimate frequency offset are studied for OFDM system and other systems are not adoptable in DBO-CSS. In this paper, we propose a new algorithm for estimation of frequency offset in DBO-CSS utilizing differential relationship between preambles by using matched filters. Section Ⅱ describes frequency offset in DBO-CSS. In Section Ⅲ, a new proposed algorithm is presented. We present the simulation results of performance on frequency offset estimation in Section Ⅳ. In Section Ⅴ, the conclusion is summarized.

Ⅱ. Frequency offset in DBO-CSS

A. The architecture based on matched filter

In DBO-CSS, a full-chirp is composed of four sub-chirps which alternate lower and upper sub-chirps. The noises in upper sub-chirp band can be removed by the filter matched for lower sub-chirp signal when the lower sub-chirp signal is used as in fig. 1. So, we can maximize the received signal-to-noise ratio (SNR) by using the matched filter. In this paper, we propose a frequency offset estimator based on the matched fil-ter to enhance the received SNR.

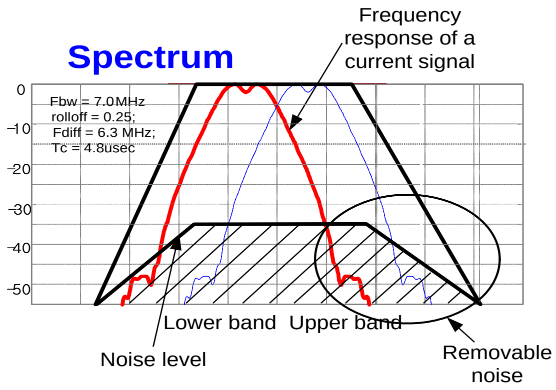

Figure 1. Spectrum of DBO-CSS signal

B. Frequency offset in DBO-CSS

In the DBO-CSS which operates in ISM band and permits frequency offsets of crystal oscillator up to ±40ppm, there can be frequency offsets as high as 200KHz as in (1). The phase rotation caused by the frequency offset in this case can be derived as (2). From (2), since the average time difference (*ΔT*) between the two symbols with differential relations is 6us, the phase rotations are ranged from -430˚ to 430˚. Because the phase Θ and 2nπ+Θcan not be distinguished by the differential phase detection only, the usual estimation method in [1] based on the auto-correlation can not estimate the exact frequency offset without phase ambiguity in this case.

$$f_{offset} = f_c \times \left(+40\,ppm - \left(-40\,ppm\right)\right)$$
$$= 2.5\times10^{9}\,Hz \times 80\times10^{-6} = 200\,KHz. \quad \textbf{(1)}$$

$$\theta = 2\pi \cdot f_{offset} \cdot \Delta T. \quad \textbf{(2)}$$

III. Proposed algorithm

According to (2), the reduction of ΔT is the only way to reduce phase rotation in order to remove phase ambiguity in case that the maximum frequency offset is not changed. When we compare the peaks of the matched filtered signals one another, each sub-chirp has the same shape as each other. Then, the frequency offset can be estimated not with the differential phase between two full-chirp signals but with the differential phase between two matched-filtered sub-chirps. The ΔT can be reduced from 6us to 1.1875us, because the time difference between each sub-chirp is 1.1875us. And, the reduced ΔT causes the phase rotations from -85.5° to 85.5°. The phase rotation less than 180° makes no ambiguity.

The phase rotation between $p_{1,peak}$ and $p_{2,peak}$ can be derived as (3). With this, we can calculate the estimated frequency offset f_{offset}. By the derivation from (4) to (7), we can estimate frequency offset without phase ambiguity.

$$p_{2,peak}p^{*}_{1,peak} = e^{j\Delta\omega_c(L)T}\,e^{j\left(-\mu\tau^2\right)} \cdot \begin{pmatrix} 2\sum_{m=-L/2}^{L/2}\sum_{n=1}^{L/2} P_{RC}\left(nT_s\right)^2 P_{RC}\left(mT_s\right)^2 \\ \cdot\cos\left(\mu\left(n+m\right)T_s\tau+\Delta\omega_c\left(n-m\right)T_s\right) \\ +2\sum_{m=1}^{L/2} P_{RC}\left(mT_s\right)^2\cos\left(-\mu mT_s\tau+j\Delta\omega_c mT_s\right)+1 \end{pmatrix} \quad (3)$$

$$2\pi\Delta f L_p T_s = \theta_{L_p} + 2\pi n \quad (4)$$

$$2\pi\Delta f L T_s = \theta_L \quad (5)$$

$$\tilde{n} = round\left(\frac{\left(\frac{L_p}{L}\theta_L - \theta_{L_p}\right)}{2\pi}\right) \quad (6)$$

$$\tilde{\Delta f} = \frac{\theta_{L_p} + 2\pi n}{2\pi L_p T_s} \quad (7)$$

Ⅳ. Simulation results

In fig. 2, we compared the proposed frequency offset estimation algorithms using (6) with the conventional method based on the auto-correlation when the SNR was 5dB. The frequencyoffset above 80KHz could not be estimated exactly by using the conventional method if there were no restriction of the frequency offset up to 200KHz. But, it is not sufficient to determine whether the proposed algorithm is efficient or not, although fig. 2 shows that the proposed algorithm works properly.

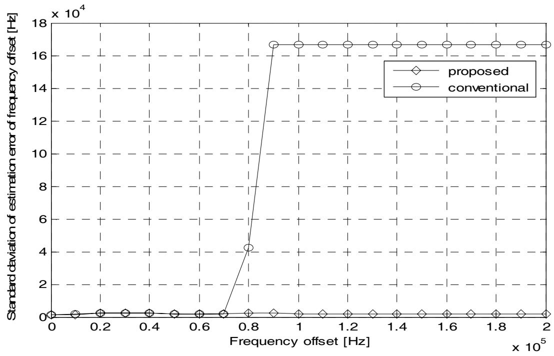

Figure 2. Standard deviation of estimation error of frequency offset followed by frequency offset. (SNR =5dB)

To verify the performance of the proposed algorithm, we have investigated the standard deviations of the estimation error. The frequency offset is fixed to 50KHz in order to compare the proposed algorithm with the conventional one based on the auto-correlation without phase ambiguity.

Ⅴ. Conclusion

We use a matched filter based frequency offset estimation algorithm and it is shown that the proposed method has good performance. We can solve the serious problems in chirp signals which are very sensitive to frequency offset. We expect that the ranging accuracy and the error performance of the DBO-CSS can be enhanced by the proposed estimation algorithm.Although we described only an initial estimation process in this paper, a fine estimation and a tracking algorithm can be made by using the proposed method with only a minor correction. And we expect that the equations derived in this paper can be also used to estimate τ, the sampling timing offset, when the frequency offset is perfectly compensated.

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