International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:6, No:9, 2012

A Side-Peak Cancellation Scheme for CBOC Code Acquisition

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Abstract—In this paper, we propose a side-peak cancellation scheme for code acquisition of composite binary offset carrier (CBOC) signals. We first model the family of CBOC signals in a generic form, and then, propose a side-peak cancellation scheme by combining correlation functions between the divided sub-carrier and received signals. From numerical results, it is shown that the proposed scheme removes the side-peak completely, and moreover, the resulting correlation function demonstrates the better power ratio performance than the CBOC autocorrelation.

Keywords—CBOC, side-peak, ambiguity problem, synchronization

I. INTRODUCTION

In binary offset carrier (BOC) modulation, the BOC signal is created by the product of the data signal, a pseudo random noise (PRN) code, and a sub-carrier. Due to its capability to resist multipath and its separated spectrum from that of the global positioning system (GPS) signal [1], the BOC has been adopted as the modulation method for the global navigation satellite systems (GNSSs) including the European Galileo and the GPS modernization [2]. In particular, it is agreed to employ composite BOC (CBOC) signals in the signal transmission for Galileo E1 band [3].

In GNSSs, a timing error from the synchronization process can result in a critical positioning error. Thus, timing synchronization is crucial for reliable GNSS-based communications. The CBOC signal synchronization is generally carried out in two stages: acquisition and tracking. In acquisition stage, first, time phase of the locally generated CBOC signal is aligned with that of the received signal within the allowable tracking range, and then, the fine adjustment is performed to achieve synchronization in tracking stage. Fig. 1 shows the autocorrelation and early-late discriminator output for CBOC signal in the acquisition and tracking stages, respectively, where T_b is the PRN code chip duration, d denotes an early-late spacing, and false alarm is the event that an autocorrelation value outside the allowable tracking range exceeds a specified threshold. From the figure, we can see that the autocorrelation has multiple side-peaks, which would increase the false alarm probability, and consequently, might cause the synchronization process converge to a false lock point. This is called the ambiguity problem.

To resolve the ambiguity problem, we propose a side-peak cancellation scheme for CBOC signals. Specifically, we first create new sub-carrier signals by dividing the conventional sub-carrier signals of CBOC signal, and then, we obtain correlations between the new sub-carriers and the received signals. Finally, we combine the correlations yielding a novel correlation function with no side-peak.

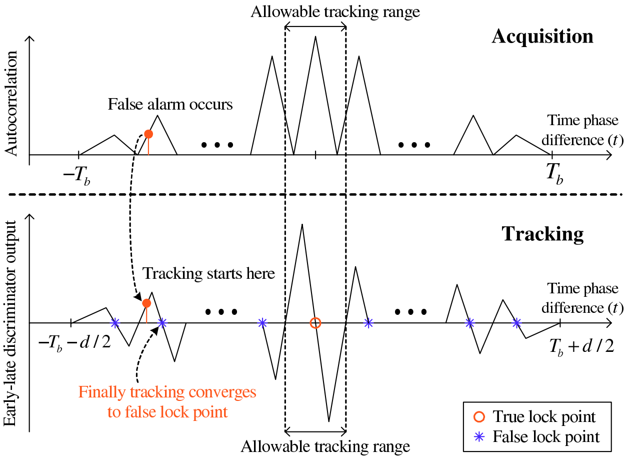

Fig. 1. Ambiguity problem in BOC signal synchronization.

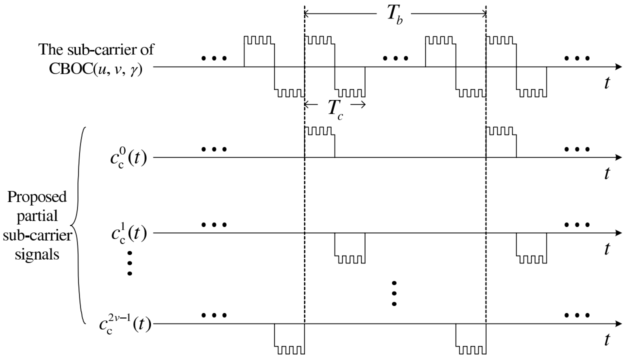

Fig. 2. Waveforms of the conventional and proposed sub-carrier signals for CBOC(u, v, γ).

The remainder of this paper is organized as follows. Section II describes the CBOC signal model and proposes a new correlation function for CBOC signals Section III presents simulation results, and finally, Section IV concludes this paper.

II. PROPOSED CORRELATION FUNCTIONS

The CBOC signal CBOC(u, v, γ) is obtained from a weighted sum of two sine-phased BOC signals SinBOC$(u, 1)$

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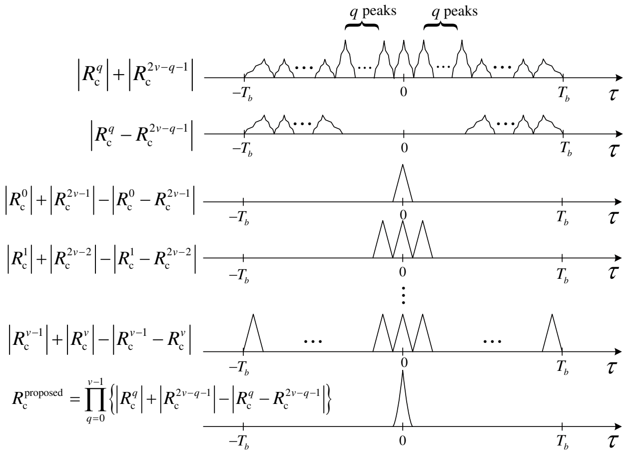

Fig. 3. The process of the proposed correlation function generation.

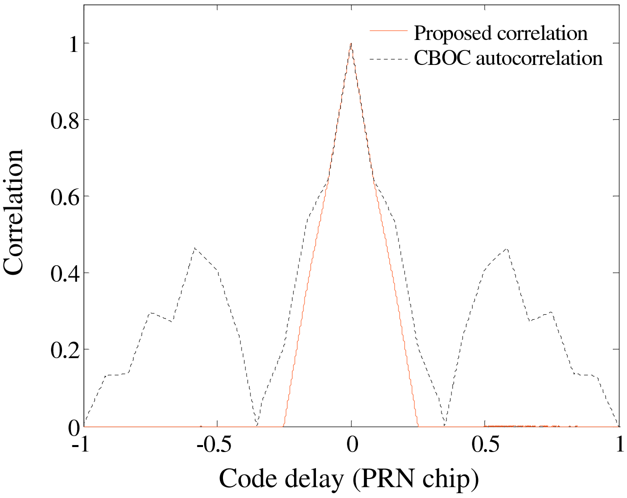

Fig. 4. The proposed correlation function and autocorrelation function of CBOC$(6,1,1/11)$.

and SinBOC$(v,1)$ with the power split ratio γ, where SinBOC(kn,n) is defined as the product of the navigation data, a PRN code, and a square wave sub-carrier $\operatorname{sgn}\{\sin(2\pi knt \times 1.023 \times 10^6)\}$. For example, CBOC$(6,1,1/11)$ is generated through the combination of SinBOC$(6,1)$ and SinBOC$(1,1)$ with spectrum components given by

$$G_{\text{CBOC}}(f)=\frac{1}{11}G_{\text{SinBOC}(6,1)}(f)+\frac{10}{11}G_{\text{SinBOC}(1,1)}(f), \quad (1)$$

where $G_{\text{SinBOC}(\cdot,\cdot)}(f)$ is the unit power spectrum density of a SinBOC defined in [4]. Thus, it is natural to consider u and v having u/v $(u>v)$ even number to guarantee orthogonality between two SinBOC (fundamentally, sub-carrier) signals, then, the CBOC(u,v,γ) signal can be expressed as

$$\begin{aligned} S_c(t) &= c(t)d(t)c_c(t) \\ &= c(t)d(t)\{\sqrt{\gamma}c_{\sin(u,1)}(t)+\sqrt{1-\gamma}c_{\sin(v,1)}(t)\}, \end{aligned} \quad (2)$$

where the CBOC sub-carrier $c_c(t)$ is the weighted sum of two square wave sub-carrier $c_{\sin(u,1)}(t)$ $(=\operatorname{sgn}\{\sin(2\pi ut\times 1.023\times 10^6)\})$ and $c_{\sin(v,1)}(t)$ $(=\operatorname{sgn}\{\sin(2\pi vt\times 1.023\times 10^6)\})$. Fig. 2 shows the waveform of the conventional and proposed partial sub-carriers for CBOC(u,v,γ), where T_c denotes the period of the sub-carrier $c_{\sin(v,1)}(t)$. In this paper, we assume that $d(t)=1$ as in a pilot channel. A GNSS often includes a pilot channel to achieve rapid synchronization in the absence of data modulation on the transmitted signal [5].

Fig. 3 shows the processes of generating the proposed correlation function for CBOC(u,v,γ), where $R_c^0, R_c^1, \cdots, R_c^{2v-1}$ denote correlations between the received CBOC(u,v,γ) signal and partial sub-carrier signals $c_c^0(t)$, $c_c^1(t)$, $\cdots$, $c_c^{2v-1}(t)$ over T_b, respectively. From the figure, we can see that the operation $|R_c^q|+|R_c^{2v-q-1}|$ for $q=0,1,\cdots,v-1$ create the correlation function with $4v-2q-1$ peaks including a main-peak and $2q$ side-peaks in the same shape as the main-peak. On the other hand, the operation $|R_c^q-R_c^{2v-q-1}|$ creates the correlation function with $4v-4q-2$ side-peaks only where the main-peak and the $2q$ side-peaks are removed. Thus, with the operation $|R_c^q|+|R_c^{2v-q-1}|-|R_c^q-R_c^{2v-q-1}|$, we can obtain a correlation function with a main-peak and $2q$ side-peaks in the same shape as the main-peak. Finally, removing $2q$ side-peaks and increasing the main-peak magnitude, we can obtain a correlation function with no side-peak as as

$$R_c^{\text{proposed}}=\prod_{q=0}^{v-1}\{|R_c^q|+|R_c^{2v-q-1}|-|R_c^q-R_c^{2v-q-1}|\}. \quad (3)$$

Fig. 4 shows the proposed correlation function and autocorrelation function of CBOC$(6,1,1/11)$, and we can observe that side-peaks can be completely removed with the proposed correlation function.

III. SIMULATION RESULTS

In this section, proposed correlation functions are compared with autocorrelation functions in terms of the power ratio between a main-peak and all peaks including the main-peak defined as

$$\text{power ratio}=\frac{\text{power in a main-peak}}{\text{power in all peaks}} \quad (4)$$

It should be noted that the power ratio of 1 means that correlation functions do not have any side-peak. For simulation, we assume the two-path channel model [6], whose impulse response is defined as

$$h(t)=\delta(t)+\alpha\delta(t-\beta), \quad (5)$$

where α $(\alpha<1)$ denotes the attenuation factor of second path which is set to 0.5 in this paper, β $(\beta>0)$ is the time difference between the first and second path, and $\delta(t)$ represents the Dirac-delta function.

Figs. 5 and 6 show the power ratio of the proposed correlation and autocorrelation function for CBOC$(6,1,1/11)$ and CBOC$(6,1,4/33)$, respectively, in a two-path channel. From the figures, we can see that the proposed CBOC correlation function has a better power ratio than that of the CBOC autocorrelation function in the two-path channel.

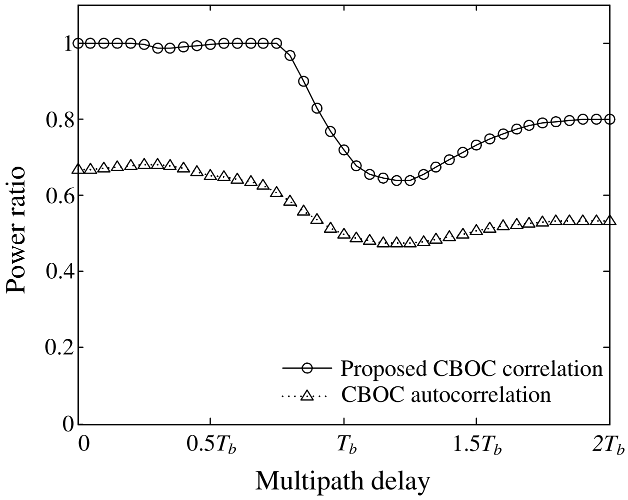

Fig. 5. Power ratio of the proposed correlation and autocorrelation functions for CBOC$(6, 1, 1/11)$ in a multipath channel.

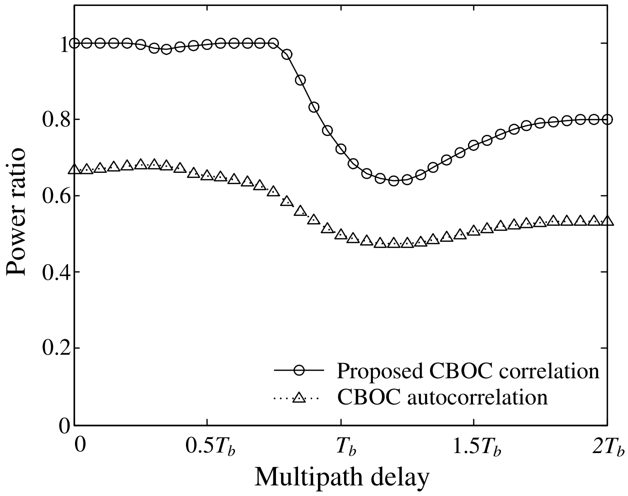

Fig. 6. Power ratio of the proposed correlation and autocorrelation functions for CBOC$(6, 1, 4/33)$ in a multipath channel.

IV. CONCLUSION

In this paper, we have proposed a side-peak cancellation scheme for CBOC code acquisition. We have first created new sub-carrier signals by dividing the conventional sub-carrier signals of CBOC signal. Then, new correlation functions with no side-peak have been generated by combining the correlation between received CBOC signal and divided sub-carrier signals. In a multipath channel, the proposed correlation functions have the power ratio less than 1; however, they have much higher power ratios than those of the CBOC autocorrelation functions.

ACKNOWLEDGMENT

This research was supported by the National Research Foundation (NRF) of Korea under Grants 2012-0005066 and 2012R1A2A2A01045887 with funding from the Ministry of Education, Science and Technology (MEST), Korea, and by the Information Technology Research Center (ITRC) program of the National IT Industry Promotion Agency under Grant NIPA-2012-H0301-12-1005 with funding from the Ministry of Knowledge Economy (MKE), Korea.

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