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A novel unambiguous composite binary offset carrier(6,1,1/11) tracking based on partial correlations☆

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ABSTRACT

This paper proposes a novel unambiguous correlation function for composite binary offset carrier (CBOC) signal tracking based on partial correlations. In the proposed scheme, first, we partition sub-carriers of the CBOC signal into partial sub-carriers, and subsequently, we obtain partial correlations by correlating the partial sub-carriers with the received CBOC signal. Finally, a novel unambiguous correlation function with no side-peak is constructed by combining the partial correlations in a specially designed way. Unlike the conventional schemes, the proposed scheme does not require any auxiliary signal and from numerical results, it is found to offer a better tracking performance than those of the conventional schemes in terms of the tracking error standard deviation (TESD) and multipath error envelope (MEE).

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1. Introduction

Because of increasing demands for more precise positioning services, various global navigation satellite systems (GNSSs) have been developed [1]. Especially, in order to operate a GNSS independent from the global positioning system (GPS), European Space Agency has developed a GNSS referred to as Galileo. Although the original binary offset carrier (BOC) signal was considered as the modulation signal for Galileo, the CBOC signal was finally adopted in Galileo E1 band in 2006, since it provides an improved signal tracking performance compared with the original BOC signal and enables Galileo signals to share the frequency band with GPS signals [2]. The CBOC signal is a weighted sum of two BOC signals, BOC(x, 1) and BOC(y, 1) and is denoted by CBOC(x, y, γ), where BOC($\cdot, \cdot$) represents a BOC signal generated by multiplying a pseudorandom noise (PRN) code and a sine-phased sub-carrier signal, γ is a power split ratio between BOC(x, 1) and BOC(y, 1), and 'x' or 'y' is the ratio of the chip period $T_c = 1/(1.023 \times 10^6)$ of the PRN code to the period of the sub-carrier. Specifically, the CBOC(6,1,1/11) signal is used in Galileo [2].

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The main drawback of the CBOC(6,1,1/11) signal is that its autocorrelation has multiple side-peaks around the main-peak, causing an ambiguity problem (i.e., the signal synchronization is completed on one of the side peaks). Thus, so far, various unambiguous schemes have been proposed for the CBOC(6,1,1/11) signal acquisition (coarse synchronization) [3–11] and tracking (fine synchronization) [12–24], of which the latter is dealt with in this paper. Authors [12–17] proposed unambiguous tracking methods for the BOC signal, and so, they are not appropriate for the CBOC signal. In [18,19], side-peak cancellation schemes were presented; however, their tracking performances are worse than that of the CBOC autocorrelation. Although improved unambiguous tracking methods using various auxiliary signals were proposed in [20–22], the improvement in tracking performance over the conventional autocorrelation is not significant, and also, the auxiliary signals increase the system complexity. Ren et al. [23] and Shen et al. [24] proposed tracking structures that do not use the autocorrelation, and thus, are free from the side-peaks; however, they have much worse tracking performances than that of the autocorrelation-based tracking.

In this paper, a novel unambiguous correlation function with a sharper main-peak is proposed to provide a better performance than those of the conventional schemes in CBOC signal tracking. Specifically, we partition the sub-carrier into partial sub-carriers, and subsequently, correlate the partial sub-carriers with the received CBOC signal, yielding partial correlations. Then, the partial correlations are combined in a specially designed way to construct an unambiguous correlation function. The proposed unambiguous correlation function is demonstrated to provide a better tracking performance than those of the conventional schemes without requiring any auxiliary signal. Although a partial correlation-based method was used in [19] also, the corresponding divide and recombination method is for BOC signals, and thus, is not appropriate for CBOC signals composed of a weighted sum of two different BOC signals, as we shall see in Sections 3 and 4.

The rest of this paper is organized as follows. In Section 2, we describe the CBOC(6,1,1/11) signal model. In Section 3, we propose a novel unambiguous correlation function with no side-peak. Section 4 compares the tracking performances of the proposed and conventional schemes, and finally, Section 5 concludes this paper.

2. Signal model

The CBOC signal $c(t)$ can be expressed as

$$c(t) = \sqrt{P} \sum_{i=-\infty}^{\infty} h_i r_{T_c}(t - iT_c) d(t) p_{sc}(t), \tag{1}$$

where P is the signal power, $h_i \in \{-1, 1\}$ is the ith chip of a PRN code with a period T, $r_\alpha(t)$ denotes the unit rectangular pulse over $[0, \alpha)$, T_c is the chip period of the PRN code, $d(t)$ denotes the navigation data, and $p_{sc}(t)$ is the square wave sub-carrier. We assume that a pilot channel for tracking is provided so that no data modulation is present during the tracking process (i.e., $d(t) = 1$). For the CBOC(6,1,1/11) signal, the sub-carrier $p_{sc}(t)$ is a weighted sum of the sub-carrier $p_{sc}^{\alpha}(t)$ of the BOC(1,1) signal and the sub-carrier $p_{sc}^{\beta}(t)$ of the BOC(6,1) signal with the power split ratio of 1/11, and thus, it is expressed as

$$p_{sc}(t) = \sqrt{\frac{10}{11}} p_{sc}^{\alpha}(t) - \sqrt{\frac{1}{11}} p_{sc}^{\beta}(t), \tag{2}$$

where $p_{sc}^{\alpha}(t) = \sum_{l=0}^{1} (-1)^l r_{T_s^\alpha}(t - iT_c - lT_s^\alpha)$ and $p_{sc}^{\beta}(t) = \sum_{m=0}^{11} (-1)^m r_{T_s^\beta}(t - iT_c - mT_s^\beta)$ with $T_s^\alpha = T_c/2$ and $T_s^\beta = T_c/12$ denoting the sub-carrier pulse periods of BOC(1,1) and BOC(6,1), respectively.

The sub-carrier of the CBOC(6,1,1/11) signal is shown in the left-hand side of Fig. 1, where the CBOC(6,1,1/11) sub-carrier consists of 12 rectangular pulses and each of which has a width of T_s^β (i.e., $T_c/12$). Thus, to generate partial correlations with a narrow peak, we unevenly partition the sub-carrier $p_{sc}(t)$ as follows:

$$p_{sc}(t) = \sum_{m=0}^{3} p_m(t), \tag{3}$$

where $p_m(t)$ is the mth partitioned sub-carrier as depicted in the right-hand side of Fig. 1 and $\{p_m(t)\}_{m=0}^{3}$ will be used to generate partial correlation functions in the next section.

3. Proposed correlation function

3.1. Unambiguous correlation function for CBOC(6,1,1/11)

The CBOC(6,1,1/11) autocorrelation shown in the left-hand side of Fig. 2 can be expressed as

$$R(\tau) = \frac{1}{PT} \int_0^T c(t)c(t+\tau)dt = \sum_{m=0}^{3} \sum_{i=-\infty}^{\infty} \frac{1}{T\sqrt{P}} \int_0^T c(t) h_i r_{T_c}(t + \tau - iT_c) p_m(t+\tau) dt = \sum_{m=0}^{3} P_m(\tau), \tag{4}$$

where $P_m(\tau)$ is the mth partial correlation between the CBOC signal $c(t)$ and $p_m(t)$. The partial correlations $P_1(\tau)$ and $P_2(\tau)$ have the zero-crossing points at $T_c/24$ and $-T_c/24$, respectively, since the pulse durations of partitioned sub-carriers

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