Two-Stage Search Scheme for High-Ordered BOC Modulation in Future GNSS

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Abstract: The future global navigation satellite system uses high-ordered binary offset carrier (BOC) modulated spreading signals. By the way, it causes a narrower main lobe and multiple side lobes in correlation function. Thus, the serial search scheme, a well-known method for code acquisition, has a number of search cells to acquire the offset, and the time to first fix will also increases. To tackle this problem, we propose a rapid code acquisition scheme when the serial search scheme is used for high-order BOC modulated spreading signals.

1. Introduction

Recently, the positioning accuracy improvement of global navigation satellite system (GNSS) has been required to provide extensive services based on the information of user location. Thus nations around the world have started to develop their own GNSS, instead of the global positioning system (GPS) of the U.S.. For this effort, GALILEO system of the UN, modernized GPS and global navigation satellite system (GLONASS) of the Russia, and COMPASS of the China and so on are testing and exploiting. Also, researches on other GNSSs are also developing rapidly [1].

The future GNSS uses binary offset carrier (BOC) modulation which is an additional modulation method to share the same center frequency among a number of GNSSs. BOC modulation separates the spectrum as modulation ratio, so systems cannot be affected by signal interferences. Thus, the GNSSs are able to use the same bands and they can be used compatibly to improve the positioning accuracy. Moreover, it has advantages in a view of frequency resource and correlation function. The main lobe in correlation function of BOC modulated spreading signal is narrower than that without BOC modulation, so it results in higher positioning accuracy [2].

GNSSs, using direct sequence/spread spectrum (DS/SS) as a physical layer for communications, require an accurate code synchronization process to measure precise positioning. The synchronization process of DS/SS systems consists of code acquisition and tracking. The code acquisition adjusts synchronization within $\pm Tc/2$ or less, where Tc means the chip period in that system. The code tracking process searches a fine synchronization offset from code acquisition results and maintains it [3]. Here, offset means time difference between pseudo random noise (PRN) code of the received signal and a replica of PRN code generated in receiver. This paper focuses on code acquisition process.

In general, serial, parallel and hybrid search schemes are widely used to achieve the code acquisition for binary phase shift keying (BPSK) modulated spreading signals. Serial search scheme operates sequentially and the measured output is compared to a threshold to decide whether its code offset is correct or not. This scheme has a low complexity, but the average time to reach code acquisition is relatively long. Parallel search scheme, on the other hand, uses many correlators, so its complexity is getting higher proportionally but the time prior to acquisition decreases. Hybrid search scheme is synthetic structure of serial and parallel schemes [3]. Among these shcemes, this paper considers a serial search scheme for its simplicity.

The code acquisition scheme for BOC modulated spreading signal can also use one of the three schemes mentioned above. However, BOC modulated spreading signal has multiple characteristics within $\pm Tc$ with correct synchronization offset. Therefore, true code acquisition have to be achieved in main lobe offsets of the correlation function to get correct synchronization [4]. The high-ordered BOC modulated spreading signal, especially, has to search using narrower step size than step size one, because its correlation function has narrow main lobe. From this, many steps search processes need and bring a increase of the time to first fix (TTFF), resulting in performance degradation of the GNSS receiver.

This paper proposes a rapid code acquisition scheme when the future GNSS uses high-ordered BOC modulated spreading signals. The remainder of this paper is organized as follows: Section 2 describes the signal structure of the BOC signal and explains the conventional code acquisition scheme and its problems in the view of code acquisition. Section 3 proposes rapid code acquisition scheme for high-ordered BOC modulated spreading signals and compares each search step. Finally, Section 4 concludes this paper.

2. Conventional Scheme: one stage search

The future GNSS uses not only BPSK modulation but also BOC modulation additionally. The modulated signal is obtained through product of a bi phase spreading PRN code with a square wave subcarrier. This square wave can either be sine or cosine phased, which leads to different signal characteristics. They are referred to as sing-BOC and cosine-BOC, respectively.

Generally, the BOC modulated spreading signal is expressed in BOC(m, n). Here, m and n are BOC subcarrier rate and PRN code rate, respectively, and both are multiple of

1.023MHz. And $m \leq n$ and BOC modulation ratio becomes $k = m/n$.

The Fig 1 shows the correlation functions of BPSK and BOC modulated spreading signals differential to k.

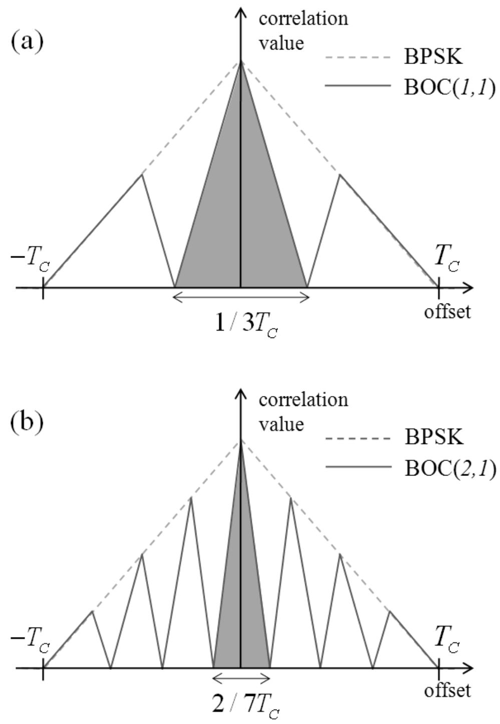

Figure 1. The correlation functions of BOC and BPSK modulated spreading signals: (a) $k = 1$ and (b) $k = 2$

Here, Tc means chip duration of GNSS. The correlation function of BOC modulated spreading signals have 1 main lobe and $(4k-2)$ side lobes within $\pm Tc$. These are caused by BOC modulation using higher k than the others to improve the positioning accuracy and share the frequency bands. At this moment, the most nervous factor to code acquisition is the existence of multiple side lobes.

The purpose of code acquisition process for BPSK modulated spreading signal is getting coarse code synchronization offset within $\pm Tc$. In this case, we can use the linear search (LS) scheme, a kind of serial search scheme, as shown in Fig 2.

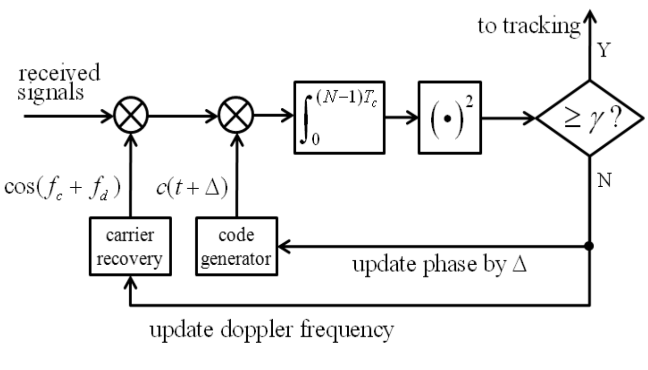

Figure 2. The structure of serial search scheme

Here, $c(t)$ is PRN code; f_c and f_d are carrier frequency and doppler frequency, respectively. Δ is search step size of LS; γ is threshold; and N means length of the PRN code.

LS scheme can calculate the correlation value using product of carrier signal and replica PRN code generated in receiver. After this process, the correlation value is compared with threshold to decide whether its offset is correct or not. At this time if correlation value is over threshold, its offset is determined as code acquisition result and the maximum search steps are being $NTc/1Tc$. This paper assumed that f_d was searched well.

Two problems can occurr when LS scheme is used for code acquisition of BOC modulated spreading signals. First, code acquisition time increases. BOC modulated spreading signals have to be searched finely owing to being narrow main lobe following k. For this reason, search steps and code acquisition time increases. Second, side lobes can be detected as a code synchronization offset instead of main lobe. This false detection is able to lead huge positioning errors, so some schemes to tackle these problems were proposed in [4, 5] but they need additional operations using correlators and others.

The code acquisition of BOC modulated spreading signals has to be decided within main lobe offset as shown in Fig 1. Therefore, search step size has to be set by a half of main lobe width or less. When this rule is adapted to BOC modulated spreading signal, the maximum search steps become $N(4k-1)$ in NTc while search step size is $1/(4k-1)Tc$ or less. Thus the search steps and TTFF increase following k [6, 7]. This paper denotes the conventional scheme as $LS(NTc, \Delta)$, and it means that LS scheme searches the code synchronization offset in NTc by Δ.

3. Proposed Scheme: two stages search

Using the conventional scheme to acquire code synchronization for high-ordered BOC modulated spreading signals needs many search steps and long time operation because search step size is narrow. To tackle these problems, this paper proposes the rapid code acquisition scheme based on two stages search shown in Fig 3(a).

Stage 1 searches a coarse code synchronization offset using LS scheme from 0 to $(N-1)Tc$ by Δ_1. This is same with the conventional scheme, but stage 1 of proposed scheme uses Δ_1 which is widely than the conventional one, so it is able to search faster than conventional scheme. The stage 1 denotes to $LS(NTc, \Delta_1)$, in this paper, and the maximum error of code synchronization is being $\pm Tc/2$ when Δ_1 is $1Tc$.

Stage 2 also uses LS scheme to search a fine code synchronization offset within the maximum error range by Δ_2 which is narrower than Δ_1. Therefore, more accurate code acquisition offset can be decided. By the way, Δ_2 has to be set $1/(4k-1)Tc$ or less because the width of main lobe in correlation function is getting narrower following k. In this paper, we assumed that Δ_2 is $1/(4k-1)Tc$.

The proposed two stages search scheme represents to combination of $LS(NTc, \Delta_1)$ and $LS(Tc, \Delta_2)$, then the final code synchronization offset becomes $\Delta_1 + \Delta_2$. And the maximum search steps of proposed scheme become $N + (4k-1)$.

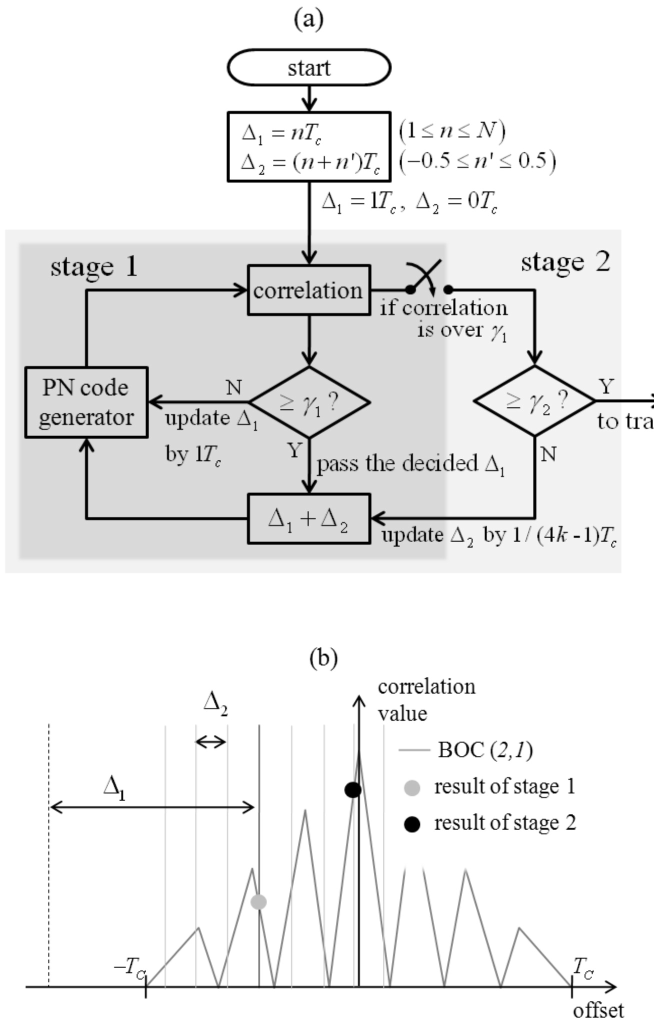

Figure 3. Two stages search scheme using LS: (a) flow graph and (b) acquired offsets

By the way, time consuming which is expressed in sum of N and k for the proposed scheme is less-dependent than the product form of conventional scheme owing to $N \gg k$. Hence, the proposed two stages search scheme can be more considerable for the future GNSS using high-ordered BOC modulated spreading signals.

And we additionally proposes another scheme for stage 2 as shown in Fig 4.

Another approach for reducing search steps in stage 2 is shown in Fig. 3. It is hop-in (HI) scheme and whole process is represented combination of $LS(NTc, \Delta_1)$ and $HI(Tc, \Delta_3)$. In HI scheme, the characteristics of BOC correlation function will be used, especially an offset between peaks and slope difference of each side lobe. If these are applied, the number of search bins can be reduced by a half than stage 2 of former proposed scheme. It uses a sign of difference between two correlation values of the acquired offset and advanced by Δ_3 from it. If the sign is positive, the acquired offset hops to delayed offset by Δ_3, while hops to advanced offset when the signa is negative. These processes continue until sign reverse occurs, and its latest offset will be decided within the mail

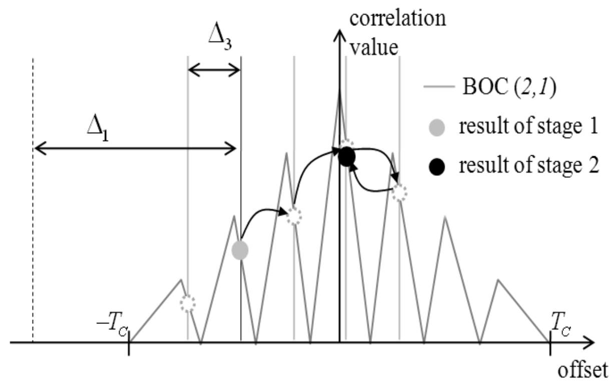

Figure 4. Two stages search scheme using LS and HI: acquired offsets

lobe offsets. Although this method can not be applied in the low signal to noise ratio, it is not dominant factor in outdoor environments.

Consequently, search steps of the proposed two stages search scheme are less than conventional one. For a simple comparison between both schemes, we use $N \gg k$ and search steps are being $4Nk$, N, respectively. From this, the proposed scheme is able to acquire the code synchronization offset faster than conventional scheme and is less dependent to k. Hence, the proposed two stages search scheme can be used for BOC modulated spreading signals which have high-ordered.

4. Conclusions

This paper proposed the rapid code acquisition scheme for BOC modulated spreading signals in future GNSS. It is based on two stages search which has different search step sizes. And we also proposed hop in scheme to reduce search steps for stage 2. We compared the proposed scheme to conventional scheme using search steps, and proposed scheme can be considered to have lower time consuming than the conventional scheme. For the further works, we will simulate the detection probability and derive a numerical analysis to measure mean acquisition time. Also, a study to improve the code acquisition performance will be continued using BOC signal characteristics and multiplexed BOC signal will be a new theme to investigate for GNSS receivers.

Acknowledgement

This work is supported by 2nd BK21 and grant No. R01-2008-000-12271-0 from the Basic Research Program of the Korea Science and Engineering Foundation.

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