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Generalized Advanced Region Correlation (G-ARC) Scheme for BOC(m, n) Modulated Code Tracking in Future GNSS

Seungsoo Yoo[1], Youngyoon Lee[2], Seokho Yoon[2], and Sun Yong Kim[1]
[1]Department of Electronics Engineering, Konkuk University,
1 Hwayang-dong, Gwanjin-gu, Seoul, 143-701, Korea,
[2]School of Information and Communication Engineering, Sungkyunkwan University,
300 Cheoncheon-dong, Jangan-gu, Suwon, Gyeonggi-do, 440-746, Korea
E-mail : kimsy@konkuk.ac.kr

Abstract: This paper proposes a generalized advanced region correlation (G-ARC) scheme for BOC(m, n) modulated code tracking, and demonstrates tracking bias and running average in static channels. The correlation values between the time-delayed pseudo noise code and received signal remain almost unchanged, due to the multipath signals being received later than a line-of-sight signal. Based on this observation, we have proposed the advanced region correlation (ARC) scheme. However, the ARC scheme uses only one ARC branch. So, the energy of the other sub-peaks is wasted. To tackle this problem, we proposed a generalized the ARC scheme that exploits all sub-peaks for BOC(m, n) modulated spreading code tracking.

1. Introduction

Today, it is possible to pinpoint the location of any user on anywhere at anytime using hand-held global navigation satellite system (GNSS) receivers and cellular phones. The United States (US) Navstar global positioning system (GPS) has become the universal GNSS since it is launched in the beginning of 1970s and reached full operational capability in 1990s. However, civil utilization of GPS has extremely been restricted because the GPS has been developed by the military purpose. To improve positioning accuracy for civil application with military and public purposes, several projects have been launched. Among them, the well-known projects are GPS modernization, called by GPS II or future GPS, and Galileo launched by European commission. The GPS II and Galileo are planing to use the same frequency bands used by current GPS in order to improve hearability and interoperability. To mitigate inter-channel interference, their signals are modulated by a special sub-carrier, called by binary offset carrier (BOC). The BOC makes the spectrum move from the center to the edge of the band. Standard BOC is represented as BOC(m, n), where m and n are the ratios of BOC frequency and spreading code rate to the same fundamental frequency, respectively. The ratio of m to n is the key parameter of BOC. The higher BOC modulation ratio is, the more separated the spectrums are. Also, multiple-peaked autocorrelation function is appeared. BOC modulation offers some advantages to compare with binary phase shift keying modulation used by current GPS. However, tracking the code synchronization is very hard due to many sub-peaks [1] -[3]. In this paper, we focus on code tracking schemes.

The most widely used code tracking scheme is the coherent delay lock loop which is well known as the early minus late correlators (EML) method. It employs the early minus late discriminator, where the advanced (early) and delayed (late) versions of the spreading signal are produced to despread the received signal. When the line-of-sight signal is only received, the EML is the best estimator among several code tracking schemes. However, in the presence of multipath signals, a tracking bias which results from the distortion in symmetry of correlation values is arisen. To tackle this problem, several methods have been proposed. They are classified as follows: the pre-processing, the post-processing, and the modified correlation with or without reference waveforms methods [4]-[8].

The pre-processing class uses the improved receiving signals which are not affected by multipath by virtue of channel estimation. It is called multipath estimating delay lock loop (MEDLL) or the multipath mitigation technology (MMT). It is the most effective tracking bias mitigation method among the other classes. However, it is very hard to implement them due to heavy complexity by channel estimation process [4], [5]. Then, the post-processing class uses the additional processed correlation values, e.g., the slope of the correlation values, the second order differentiated values, and so on. Its complexity is in the middle of them. However, it is very sensitive to channel variation caused by differential-typed operations [1]. Finally, the modified correlation class uses the values from some modified correlators with or without reference waveforms. They can reduce the tracking bias effectively with a little complexity increase [6]-[8]. In this paper, we focus on the modified correlation-type code tracking method for the future GNSSs.

We have observed that the correlation values between the time-advanced pseudo noise code and received signal are less distorted by multipath signals, assuming that the multipath signals arrive at the receiver later than a line-of-sight signal. Based on this observation, we have proposed a code tracking scheme called advanced region correlator (ARC) in [9]. The ARC scheme uses the first sub-peak at advanced offset region in correlation domain. Its tracking accuracy is better than that of the conventional scheme, delay lock loop or EML. It is very advantageous for some GNSSs that uses BOC($1, 1$). However, when higher BOC modulation ratio is used, energy of other sub-peaks except for the first sub-peak is wasted. If we can fully use the wasted energy of some sub-peaks, then code timing will be more accurate. Thus, in this paper, we propose a generalized ARC (G-ARC) scheme for BOC(m, n) modulated spreading signal based on the ARC scheme.

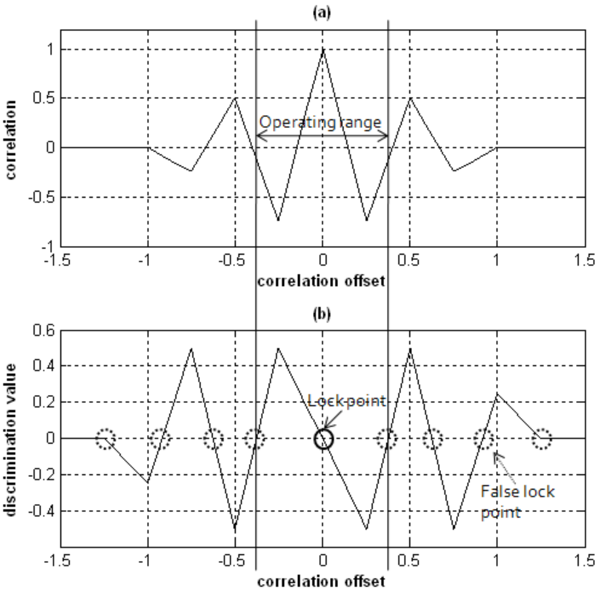

Figure 1. The BOC$(2, 1)$ modulated spreading signal: (a) Correlation function and (b) discrimination values

This paper is organized as follows. Section 2 introduces BOC(m, n) modulated spreading signals and explains their property in multipath environments. In Section 3, we observe the asymmetric property of correlation function in multipath environment and propose a code tracking scheme based on the ARC scheme. Then, in Section 4, the simulation results demonstrate that the proposed scheme outperforms the conventional scheme in terms of the tracking bias and its running average in static channels. Finally, Section 5 concludes this paper.

2. BOC(m, n) Modulated Spreading Signals

BOC multiplies a subcarrier as well as a code onto the carrier. The standard form of BOC modulation is BOC(m, n) where m and n are the ratio of BOC frequency and spreading code rate to the same fundamental frequency, respectively. The key parameter of BOC modulation is modulation ratio (R_{BOC}) which is the ratio of m to n. The higher BOC modulation ratio is, the more separated the spectrums are. On the other hand, the problem arises from the multi-peaked correlation function and the potential for a receiver encountering 'false lock' [3], [4]. In this paper, we assume that the correct correlation offset is $\tau = 0$. The several sub-peaks are appeared symmetrically at advanced and delayed offset region. And, the number of sub-peaks and false lock points depend on BOC modulation ratio. The number of sub-peaks ($2L$) and false lock points (P) are $(4R_{BOC} - 2)$ and $2(L + 1)$, respectively.

The correlation function of BOC$(2, 1)$ modulated spreading signal and its discrimination values are shown as in Fig. 1.

In Fig. 1, we can confirm that $R_{BOC} = 2$, $L = 3$, and $P = 8$. In Fig. 1-(b), 'the lock point' means the offset point

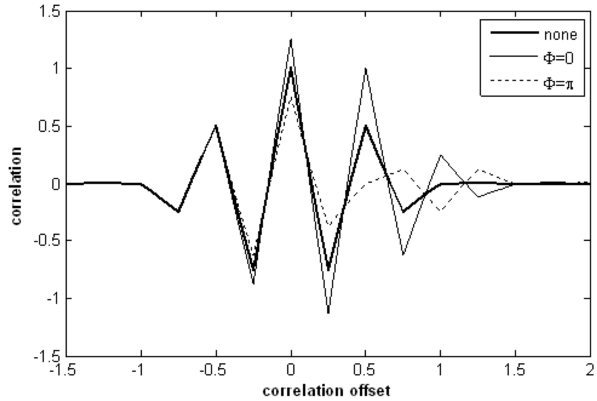

Figure 2. Asymmetric correlation function by multipath effects

of the correct correlation. The operating range is the offset interval to converse into the correct lock point. Namely, it is the interval between the nearest incorrect lock points around the main peak. If code offset converses into incorrect offset, then information data recovering is very difficult. Also, code tracking loop is not able to converse into correct offset after conversing into incorrect offset. The wider operating range is, the more reduced the complexity of acquisition and tracking level can be.

And, another performance criterion is code tracking bias which is code tracking error remaining after code lock by multipath effects. It is the dominant error source among many error sources in global navigation satellite systems, e.g., ionospheric and tropospheric errors, clock drift, and Doppler effect. Among these, they except for multipath effect are completely rejected by differential techniques. Thus, to mitigate multipath effect, several schemes have been proposed. As the one solution among them, we have proposed the ARC scheme for code tracking of BOC$(1, 1)$ modulated spreading signals in [9]. However, when higher BOC modulation ratio is used, the energy of sub-peaks except for the first sub-peak is wasted. If we can fully use the wasted energy of sub-peaks, code timing will be more accurate. From this idea, in this paper, we propose a generalized ARC (G-ARC) scheme for BOC(m, n) modulated spreading signal through modifying the ARC scheme.

3. The Proposed Scheme: G-ARC

In static channels where noise is free and a line-of-sight and only one multipath signals are received, the correlation function of BOC modulated spreading signal depends on difference of amplitude (A), phase (Φ), and relative delay (τ_Δ) between a line-of-sight and a multipath signals. When $A = 0.5$, $\Phi \in \{0, \pi\}$, and $\tau_\Delta = 0.5T_C$, the distorted correlation function is as Fig. 2.

Here, 'none' means only receiving a line-of-sight signal. As shown in Fig. 2, the correlation values around the sub-peak corresponding to advanced offset region would be less distorted by a multipath signal compared with those corresponding to delayed offset region, since the multipath signals

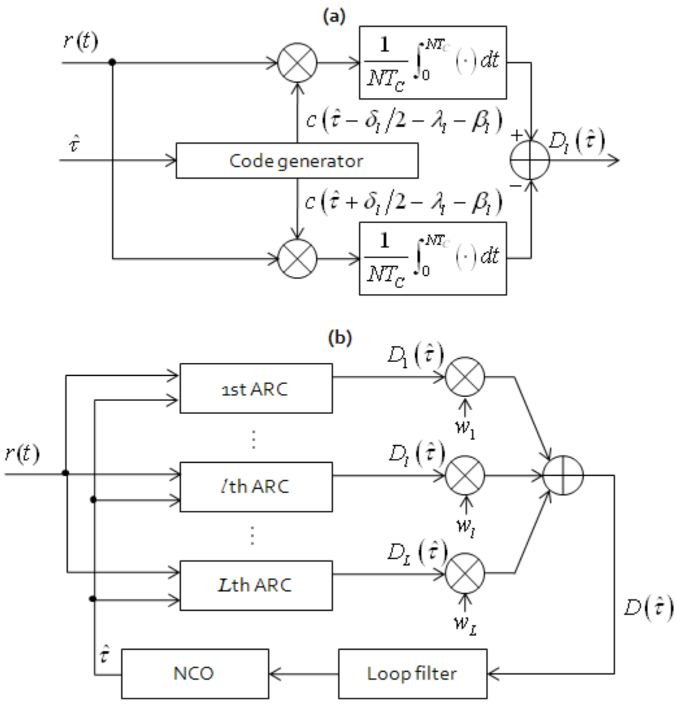

Figure 3. The structure of proposed scheme: (a) The lth ARC branch and (b) generalized-ARC (G-ARC)

arrive after the line-of-sight signal does. This observation is the key motivation of the proposed scheme. Based on this, we have proposed the advanced region correlation (ARC) scheme for BOC$(1, 1)$ modulated spreading signal. In this paper, we propose an advanced ARC scheme for common BOC(m, n) modulated spreading signal. The novel scheme is a generalized ARC (G-ARC) scheme, and its structure is as Fig. 3.

Here $r(t)$ is received signal; $c(\tau)$ is spreading code, and its length is NT_C; T_C is spreading code chip period; $D_l(\tau)$ and δ_l are discrimination value at offset τ and spacing between early and late corrlators of lth ARC branch, respectively; λ_l is the constant offset of the lth sub-peak in advanced offset region; β_l is asymmetric compensation factor of the lth ARC branch; w_l is weighting factor and is explained with (2); $\hat{\tau}$ is the estimated offset; and NCO denotes the numerically controlled oscillator.

From [9], the correlation values at advanced offset region are asymmetric due to offset of each sub-peak even though the line-of-sight signal is only received as Fig. 4.

Here, E_l, P_l, and L_l are position of early, prompt, and late arms of lth ARC branch. And, the asymmetric compensation factor for lth sub-peak is used as follows:

$$\beta_l = \lambda_l - \frac{\left(\frac{z_{l+1}+z_l}{2} - \lambda_l\right)\delta_l}{z_{l+1} - z_l}, \tag{1}$$

where z_l is lth zero-crossing offset in advanced correlation offset region, and $z_L = -T_C$.

The weighting factor can be obtained by using standard least squares algorithm:

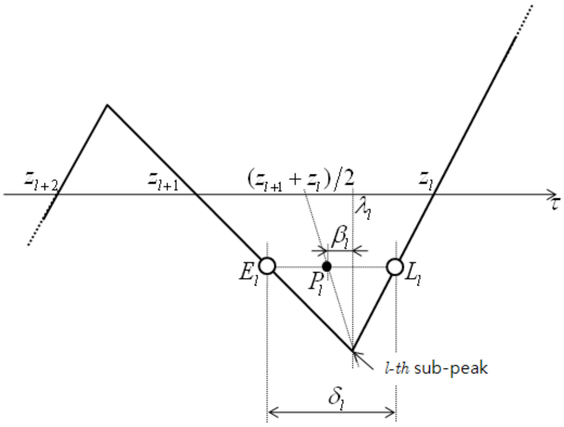

Figure 4. The lth sub-peak and its asymmetric compensation factor

$$\mathbf{w} = \left(\mathbf{D}^{\mathbf{T}}\mathbf{D}\right)^{-1}\mathbf{D}^{\mathbf{T}}\mathbf{d}_{\mathbf{opt}}, \tag{2}$$

where, $\mathbf{w} = [\mathbf{w_1} ... \mathbf{w_L}]^{\mathbf{T}}$ is $(L \times 1)$ weighting vector; $\mathbf{D} = [\mathbf{d_1} ... \mathbf{d_L}]$ is $(D \times L)$ ARC discrimination matrix; $\mathbf{d_l} = [\mathbf{d_{l,1}} ... \mathbf{d_{l,D}}]^{\mathbf{T}}$ is $(D \times 1)$ discrimination vector of lth ARC; $\mathbf{d_{opt}}$ is the optimum discrimination vector from [10]; D is the number of the sampled points; and superscript -1 and T are inverse and transpose operations.

4. Simulation Results

The tracking performance of G-ARC scheme is evaluated in terms of the tracking bias and running average with the following simulation conditions: a line-of-sight and one multipath signals are received, and their normalized powers are 1 and 0.5, respectively; $R_{BOC} \in \{1, 2\}$; and $\delta = T_C/24$.

Figs. 5 and 6 show the tracking bias and running average of the conventional (EML) and proposed G-ARC schemes as a function of the relative delay between a line-of-sight and the multipath signals.

In Figs. 5-(a) and 6-(a), $\Phi = 0$ and $\Phi = \pi$ represent that the phase difference between line-of-sight and multipath signals are in-phase and out-of-phase, respectively. The performance of G-ARC scheme is the same the one of ARC scheme using BOC(n, n) as Fig. 5. From Fig. 6 and [9], we can see that the G-ARC scheme has smaller tracking bias and the running average than those of the other schemes. This can be explained as follows. The proposed G-ARC scheme uses several ARC branches where correlation values are relatively less distorted by the multipath signals. On the other hand, the ARC scheme uses only one ARC branch which applies the most distorted correlation values by multipath signals among the correlation values of ARC branches.

Also, the operating range of the proposed G-ARC scheme is wider than the conventional scheme, because the G-ARC scheme uses several ARC branches. On the other hand, the the proposed scheme is more complex caused by using many correlators.

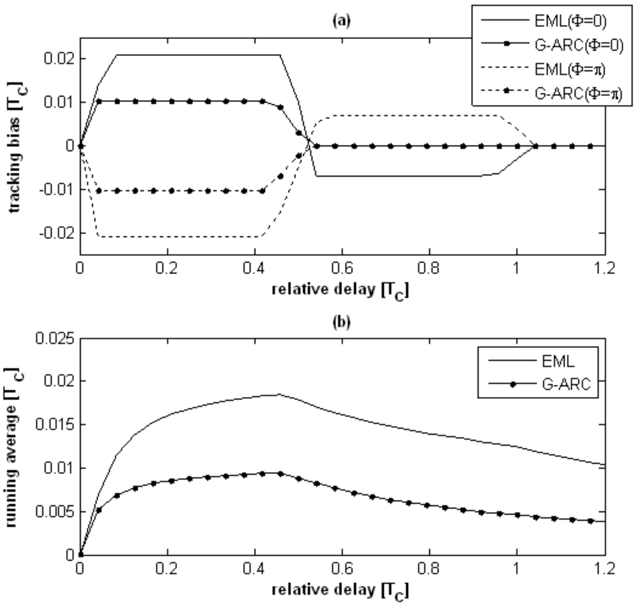

Figure 5. BOC$(1, 1)$ modulated spreading signal is used: (a) Code tracking bias and (b) running average

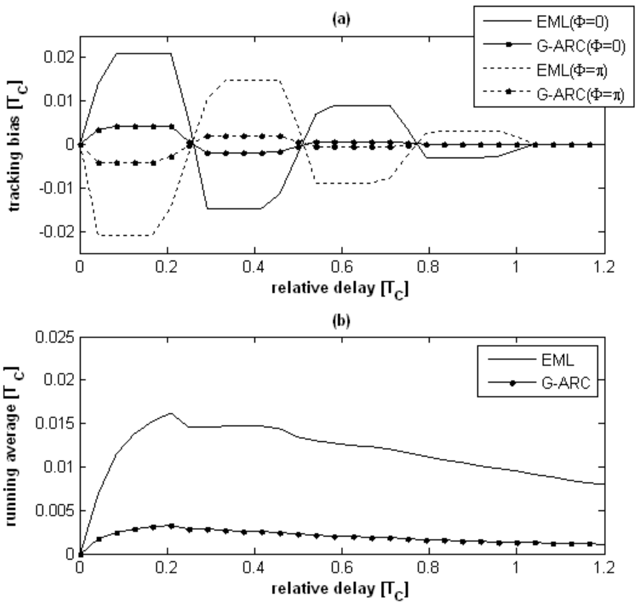

Figure 6. BOC$(2, 1)$ modulated spreading signal is used: (a) Code tracking bias and (b) running average

5. Conclusions

In this paper, we have addressed a generalized advanced region correlation (G-ARC) scheme for BOC(m, n) modulated spreading signal. First, we have observed that the correlation values between the time-delayed pseudo noise code and received signal remain almost unchanged, due to the multipath signals being received later than a line-of-sight signal. Based on this observation, we had proposed the advanced region correlation (ARC) scheme for BOC$(1, 1)$ modulated spreading signal in [9]. Then, in this paper, its generalized version have proposed. Through the simulation, we have confirmed that the tracking accuracy of the proposed scheme is better than that of the EML and ARC schemes in terms of tracking bias and its running average.

Acknowledgement

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