GNSS Signal Acquisition in the Presence of Bit Transition

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Abstract

In the acquisition block of a real time receiver for satellite communication, bit transition due to the navigation message may cause a correlation peak splitting, which will probably lead to a wrong estimation of Doppler shift and code phase delay. In this paper, the impact of bit transition on the acquisition is analyzed and a scheme named modified time parallel acquisition (MTPA) with the discrete Fourier transform (DFT) operation applied to, is proposed to solve the problem. The simulation results and performance curves show that the MTPA scheme is promising.

Keywords: bit transition, correlation peak splitting, time parallel acquisition

1. Introduction

In a GNSS receiver, the acquisition block gets a rough estimation of the Doppler shift and code delay of satellites in view. A conventional GNSS receiver usually takes a serial acquisition scheme. However, with the performance close to a real-time acquisition, parallel schemes based on fast Fourier Transform (FFT) become popular[1].

In the time domain parallel acquisition, a bit transition to the navigation message may cause a loss of correlation peak, leading to a wrong estimation. An algorithm named block accumulating semi-coherent integration of correlations (BASIC) is proposed to solve this problem[2]. In [3], all the possible transition places with secondary code constraints are detected based on the FFT sign search. Based on the fact that the total useful signal energy remains unchanged in the presence of the bit transition, the problem can be solved from an energy view[4]. Based on the fact that the total useful signal energy remains unchanged in the presence of the bit transition, the problem can be solved from an energy view[5].

In this paper, the bit transition problem in time parallel acquisition scheme of GNSS signals is focused on. The problem is analyzed and a modified time parallel acquisition (MTPA) scheme is proposed in order to solve the transition problem and make a fast acquisition at the same time. The simulation results and performance analyses of the MTPA scheme are also presented.

2. Signal Model

Suppose the IF (intermediate frequency) signal of a single satellite is modeled as

$$r(t)=\sqrt{P_R}c(t-\tau)s_b(t-\tau)d(t-\tau)e^{j[2\pi(f_{IF}+f_d)t+\varphi]} \quad (1)$$

where, P_R is the received power; $c(t-\tau)$ is the periodic satellite code, τ is the code delay; $s_b(t)$ is the subcarrier; $d(t)$ is the navigation message or a

secondary code; f_{IF} is the intermediate frequency at the front-end output; f_d is the Doppler shift and φ is a random phase.

Suppose that the sampling rate is f_s, the realistic model of the signal at the acquisition input is

$$s(n) = r(n) + w_i(n) + jw_q(n) \qquad (2)$$

where, $r(n) = r(nT_s)$; $w_i(n)$ and $w_q(n)$ are two Gaussian noise terms with variance:

$$\sigma_i^2 = \sigma_q^2 = N_0 B_r / 2 = N_0 f_s / 4 \qquad (3)$$

3. Bit Transition Problem Analysis

Suppose that the number of the input signal to be integrated is *N*, the local signal is modeled as

$$l(n) = c(nT_s - \hat{\tau}) s_b(nT_s - \hat{\tau}) e^{-j2\pi(f_{IF} + f_d)nT_s} \qquad (4)$$

where, $\hat{\tau}$ is the estimate of the code delay and $\hat{f}_d$ is the estimate of the Doppler shift.

Define that $r_N(n) = s(n) e^{-j2\pi(f_{IF} + \hat{f}_d)nT_s}$, the correlation function is

$$R_{r,l}(\tau, f_d) = \sum_{n=0}^{N-1} r_N(n) c(nT_s - \hat{\tau}) s_b(nT_s - \hat{\tau}) \qquad (5)$$

3.1. Bit Transition Problem

In case of bit transition, $d(nT_s)$ becomes a two-pulse signal, as shown in Fig. 1, where N_τ is the delay expressed in the discrete time notations and *N* is one satellite period discretely.

When $f_d = \hat{f}_d$ and ignore the noise, the correlation function becomes

$$R_{r,l}(\tau, f_d) = e^{j\varphi}[N_\tau - (N - N_\tau)] \qquad (6)$$

The correlation peak disappears when the bit transition occurs at the middle of the code period.

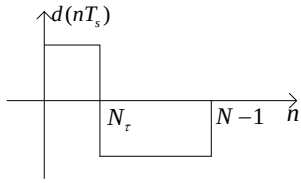


Fig. 1: Data bit $d(nT_s)$, $N_\tau = \lfloor \tau / T_s \rfloor$.

3.2. MTPA Scheme

In order to solve the bit transition problem, define two signals as

$$r_{2N}(n) = \begin{cases} r_N(n) & n = 0 \sim N-1 \\ 0 & n = N \sim 2N-1 \end{cases} \qquad (7)$$

$$l_{2N}(n) = \begin{cases} l_N(n) & n = 0 \sim N-1 \\ -l_N(n) & n = N \sim 2N-1 \end{cases} \qquad (8)$$

Then the circular correlation function of $r_{2N}(n)$ and $l_{2N}(n)$ is

$$\begin{aligned} Corr(m) &= \sum_{n=0}^{2N-1} l_{2N}(n) r_{2N}(n+m) \\ &= IDFT\{L_{2N}^*(k) R_{2N}(k)\}(m) \end{aligned} \qquad (9)$$

where, $m = 0, 1, ..., 2N-1$; $L_{2N}(k)$ and $R_{2N}(k)$ are the Fourier transform results of $l_{2N}(n)$ and $r_{2N}(n)$.

As observed from (9), the location of the bit transition can be detected in the first *N* values of $Corr(m)$, while $m = 0$ means that no bit transition exists. And $Corr(m)$ is characterized as

$$Corr(m) = -Corr(m-N) \quad m = N \sim 2N-1 \qquad (10)$$

As $L_{2N}^{*}(k)R_{2N}(k)$ can be rewritten as

$$L_{2N}^{*}(k)R_{2N}(k)=0 \qquad k=2p \tag{11}$$

$$L_{2N}^{*}(k)R_{2N}(k)=2\times\{DFT(r_N(n)e^{-j\frac{2\pi}{2N}n}) \tag{12}$$

$$\times DFT(l_N(n)e^{-j\frac{2\pi}{2N}n})\}(p) \quad k=2p+1$$

And $r_N(n)e^{-j\frac{2\pi}{2N}n}$ can be rewritten as

$$r_N(n)e^{-j\frac{2\pi}{2N}n}=s(nT_s)e^{-j2\pi(f_{IF}+f_d+\frac{f_s}{2N})nT_s} \tag{13}$$

So the first N values of $|Corr(m)|$ are

$$|Corr(m)|=|IDFT\{T_{2N}(k)\}(m)| \tag{14}$$

where $T_{2N}(k)$ is defined as

$$T_{2N}(k)=\{DFT(r_N(n))\square DFT(l_N(n)e^{-j\frac{2\pi}{2N}n})\}(k) \tag{15}$$

Equ. (14) means searching the code delay in presence of the bit transition at the Doppler shift cell of $f_d-f_s/2N$. Then the modified time parallel acquisition (MTPA) scheme is shown in Fig. 2.

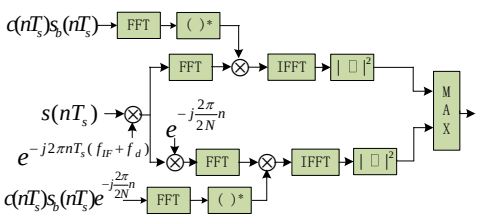
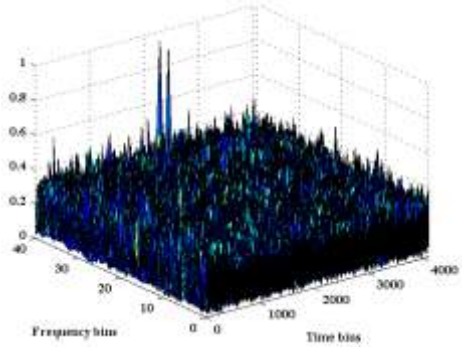


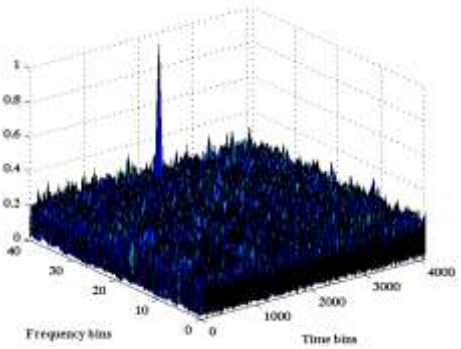
Fig. 2: The MTPA scheme.

The MTPA scheme searches the code delay without a bit transition at the Doppler shift cell of $\hat{f}_d$ and searches the code delay with a bit transition at the Doppler shift cell of $f_d-f_s/2N$. The two results are compared to determine the correct code delay and whether a bit transition occurs.

A comparison of the acquisition results between the conventional time parallel scheme and the MTPA scheme is shown in Fig. 3. The results are in the case of the Galileo E1 band pilot signal with a bit transition of the secondary code. The integration time is 4ms, the code delay is 2ms and $C/N_0=40dB/Hz$.



(a). Result of the conventional scheme.



(b). Result of the MTPA scheme.

Fig. 3: Correlation results of the conventional and our MTPA acquisition schemes.

4. Performance Analysis

In this section the performance of the MTPA scheme is presented. The acquisition of Galileo E1 band signals is

performed for example. Fig. 4 shows the ROC (region of convergence) curves with the MTPA scheme. And Fig. 5 shows the detection performance in the examined C/N_0 ranges of different false alarm probability P_{fa}. The code delay is always $\tau=2ms$ and the Doppler shift is $f_d=4KHz$. The presence of the bit transition in the signal is random.

The results show that the MTPA scheme does not cause a degradation of acquisition performance and solves the bit transition problem at the same time.

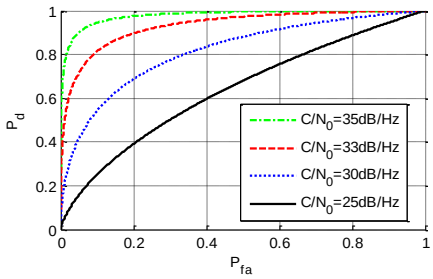


Fig. 4: ROC curves of the MTPA scheme

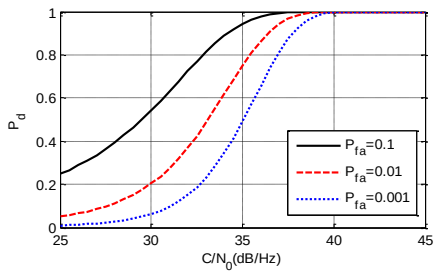


Fig. 5: Detection Probability of the MTPA scheme

5. Conclusions

From the results shown in the previous sections, it appears that the acquisition methods collide with the problem of the bit transition. The MTPA scheme is proposed to perform a fast acquisition and solve the bit transition problem at the same time. Theoretical considerations and simulation results show that the proposed method is promising.

6. Acknowledgement

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7. References

[1] K. Borre, D. M. Akos, N. Bertelsen, P. Render and S. H. Hensen, "A Software-defined GPS and Galileo receiver," *Birkhäuser*, 2007.

[2] C. Yang, T. Nguyen, E. Blasch, and M. Miller, "Post-correlation semi-coherent integration for high-dynamic and weak GPS signal acquisition," *in Proc. IEEE/ION PLANS 2008*, pp. 1341-1349, 2008.

[3] D. Borio, "FFT sign search with secondary code constraints for GNSS signal acquisition," *in IEEE Trans. On Aerospace Electronic System*, pp.1227-1240, 2009.

[4] X. Zhu, X. Chen, G. Tu and Z. LI, "New high-sensitivity acquisition method and implementation for GNSS software receiver," *in Systems Engineering and Electronic*, pp. 2055-2058+2075, 2009.

[5] L. L. Presti, X. Zhu, M. Fantino and P. Mulassano, "GNSS signal acquisition in the presence of sign transition," *in IEEE J. Sel. Top. Sign. Proces*, pp. 557-570, 2009.