A study of the influence of DLL parameters on the GNSS positioning accuracy

I A Petrov

Peter the Great St. Petersburg Polytechnic University, Polytechnicheskaya 29, St. Petersburg 195251, Russia

E-mail: petrov.ia@edu.spbstu.ru

Abstract. We propose to estimate the best DLL parameters for GNSS receiver through the simulation modeling. Our simulation model estimates mean standard deviation of the time synchronization error at different SNRs and with different receiver-satellite system dynamics. By using real GPS records, it was shown that DLL parameters have a significant influence on the positioning accuracy.

1. Introduction

In modern positioning systems the pseudorange method is widely used [1–13]. Time synchronization is possible with reference to the samples of the analyzed signal which is formed using the pseudorandom sequence called for example in GPS (Global Positioning System) CA-code (Coarse/Acquisition code), therefore without using sophisticated DLL (Delay Locked Loop) the time synchronization error $\Delta t$ is up to half the sampling interval $T_s$ and its absolute value is determined by the signal sampling rate (figure 1). When using sampling rate twice more than chip rate for GPS (that is $F_s = 2.046$ MHz) possible inaccuracy in determining the distance from the satellite to the receiver is equal to about 70 m, that means inaccuracy in receiver coordinate determining is of the same order [1–3].

One of the ways to improve the accuracy of determining coordinates is to use loop filters in the GNSS (Global Navigation Satellite System) signal tracking unit [1-3, 7–8]. This method allows to obtain the fine-resolution in time synchronization which gives more accurate estimates of the coordinates of the receiver. Despite the fact that the algorithm of using loop filters in the GNSS signal tracking unit is described in many sources, for example [1–3, 7–8], nevertheless as far as we know its
specific implementation with indication of all parameters is not specified anywhere. Therefore the aim of the work is to investigate the influence of DLL parameters on the accuracy of determining the coordinates. Objectives are as follows:

1. To develop a simulation model for tracking the GNSS signal using loop filters.
2. To investigate the effect of DLL parameters on the SD (Standard Deviation) of the time synchronization error at different SNRs (Signal-to-Noise Ratio) and with different receiver-satellite system dynamics.
3. To investigate the influence of DLL parameters on the accuracy of determining the coordinates by processing the record of the GPS signal.

In the work all simulations and signal processing are implemented in MATLAB.

2. Simulation Modeling Overview

2.1. DLL Overview

Tracking of GNSS signals is carried out using loop filters. A generalized time synchronization scheme with using DLL is presented in figure 2 [3, p. 173, Figure 5.13]:

![Time Synchronization Block Diagram](image)

Figure 2. Time synchronization block.

At first, the digital signal is transferred from the intermediate frequency to the zero frequency to form quadratures. Then knowing the initial time synchronization (from the detection), we calculate three signal correlations with CA-code for the prompt (P), early (E) and late (L) samples of the signal. Further we perform integration and dumping in each correlation branch of each quadrature and feed the obtained values to the discriminator and then to the loop filter (LPF – Low-Pass Filter). The resulting time synchronization error is fed to the NCO (Numerically Controlled Oscillator) which corrects the time synchronization.

2.2. DLL Simulation

It was considered two discriminators to compare them with each other: a coherent and non-coherent. Expressions for calculating the error of each discriminator are presented in [3, p. 174, Table 5.5]. The order of the LPF was chosen to be equal to 2. It is based on the considerations that higher order filters are unstable in the time synchronization unit; the second order provides both the stability of the unit of time synchronization, and sensitivity to relative velocity in the receiver-satellite system [1–3, 7–8].
In model we used maximum speed equal to 900 m/s. Two situations were simulated: worst (high) – relative speed is maximal; most probable (medium) – the relative speed is equal to half of the maximum possible. Several values of SNR have been considered for clarity in the presentation of simulation results. The initial time synchronization error in each experiment is a random value uniform distributed on the interval $[-1/2R; 1/2R]$, where $R$ is a signal resampling factor (we used the minimum possible resampling factor which is $R = 2$ [14]).

Note that during the simulation the frequency and phase adjustment loops were turned off, as only the time adjustment loop was investigated (it was assumed that the phase and frequency estimates are precise). For each set of parameters we conducted 100 experiments to estimate the mean SD of the time synchronization error.

2.3. Processing GPS Signal Record

Test GPS signal was recorded by stationary receiver. After coherent detection five the most powerful satellites were selected for GNSS positioning. The parameters of the loop frequency and phase adjustment were chosen in such a way as to achieve a mode of synchronism in frequency and phase. In the process of adjustment non-coherent bit synchronization was additionally performed at the beginning of the tracking procedures.

3. Results

3.1. DLL Simulation Results

The simulation results namely the minimum SD of the time synchronization error for each considered situation are presented in Table 1.

Table 1. The optimal DLL parameters according to the criterion of the minimum of the SD of the time synchronization error with different SNRs and different receiver-satellite system dynamics.

| $\sigma_{AWGN}$ | Coherent discriminator | Non-coherent discriminator |
|-----------------|------------------------|----------------------------|
|                 | $T_{int}$ (ms) | $B_{DLL}$ (Hz) | SD (samples) | $T_{int}$ (ms) | $B_{DLL}$ (Hz) | SD (samples) |
| High $\sigma_{AWGN} = 0.42$ | 20 | 2 | 0.0267 | 20 | 2.25 | 0.0397 |
| Medium | 10 | 1.25 | 0.0237 | 10 | 1.25 | 0.032 |
| High $\sigma_{AWGN} = 0.6$ | 20 | 2.5 | 0.0434 | 10 | 2.75 | 0.0587 |
| Medium | 20 | 1.25 | 0.031 | 20 | 1.25 | 0.0409 |
| High $\sigma_{AWGN} = 0.85$ | 20 | 2.5 | 0.0643 | 20 | 2.75 | 0.0827 |
| Medium | 20 | 1.5 | 0.0504 | 20 | 1.5 | 0.0626 |
| High $\sigma_{AWGN} = 1$ | ~ | ~ | ~ | 20 | 3 | 0.1023 |
| Medium | 20 | 2 | 0.0807 | 20 | 1.75 | 0.0786 |
| High $\sigma_{AWGN} = 1.5$ | ~ | ~ | ~ | 20 | 4 | 0.1873 |
| Medium | ~ | ~ | ~ | 20 | 2.25 | 0.1351 |

$^1T_{int}$ – integration time of DLL.

$^2B_{DLL}$ – band of LPF.
To investigate the effect of DLL parameters on the SD of the time synchronization three-dimensional graphs were constructed which are presented below (along the X axis – DLL integration time, Y axis – LPF band, Z axis – SD of time synchronization errors in samples).

Results with using coherent and non-coherent discriminator are shown in figure 3 and figure 4 respectively (highly dynamic system):

![Figure 3. Coherent discriminator.](image1)

![Figure 4. Non-coherent discriminator.](image2)

The results of the DLL operation at different LPF bandwidths using coherent and non-coherent discriminators are presented in figure 5 and figure 6 respectively (medium dynamic situation):

![Figure 5. Coherent discriminator.](image3)

![Figure 6. Non-coherent discriminator.](image4)

The results of the DLL operation with degradation of the SNR by 11 dB are presented in figure 7 and figure 8 respectively (the system was at medium dynamic, it was used a non-coherent discriminator):

![Figure 7. Coherent discriminator.](image5)

![Figure 8. Non-coherent discriminator.](image6)
3.2. **GPS Record Processing Results**

Clouds of positions when used in a DLL coherent and non-coherent discriminator are shown in figure 9 and figure 10 respectively ($T_{int} = 10$ ms, $B_{DLL} = 4$ Hz):

![Figure 9. Coherent discriminator.](image)

![Figure 10. Non-coherent discriminator.](image)

Clouds of positions when used in a DLL LPF with a smaller bandwidth compared with the previous case are shown in figure 11 and figure 12 respectively ($T_{int} = 10$ ms, $B_{DLL} = 2$ Hz):

![Figure 11. Coherent discriminator.](image)

![Figure 12. Non-coherent discriminator.](image)

Clouds of positions when using a DLL with more time integration than in the previous case are shown in figure 13 and figure 14 respectively ($T_{int} = 20$ ms, $B_{DLL} = 2$ Hz):
4. Conclusions

The use of coherent discriminator gives a not significant gain on the resulting SD for cloud of positions over the use of non-coherent discriminator. Though coherent discriminator can be used only when we have reached the phase lock.

The more dynamic the receiver-satellite system the greater SD of the time synchronization, as well as the wider LPF band is needed to catch system changes. The use of non-coherent discriminator requires a wider band of the loop filter compared to the coherent use case since the non-coherent discriminator captures more noise which prevents it from entering sync mode with a narrow LPF band. Decreasing the SNR increases both the SD of the time synchronization error and the optimal bandwidth of the loop filter.

The wider LPF band the more noise enters the band and therefore the SD of the coordinates increases. However too small bandwidth may not keep pace with the dynamics of the receiver-satellite system which means there is some trade-off that is in accordance with [1-13]. Bandwidth value has a significant effect on SD of the coordinates of the receiver (greater influence compared with the use of a coherent discriminator versus non-coherent).

When using a coherent discriminator, the longer integration time and the greater the SNR, the more accurately receiver coordinates are determined. When working with non-coherent discriminator an increase in time of integration is not only increases the SNR, but also captures more noise, so for good SNR when using non-coherent discriminator (as with coherent) there is no particular difference in the resulting SD of coordinates at different integration times. However with a small SNR a small number of accumulations may simply not be enough for the system to enter sync mode. It is also interesting that for large SNRs it is more advantageous to clock the system (when using non-coherent discriminator) faster (reducing the integration time) in order to keep up with the system dynamics.

It is important to note that the higher SNR the less results variation when comparing various DLL parameters which is theoretically described by a theorem (boundary) Rao–Cramer [1–3].

Acknowledgments

Grateful to A.L. Gelgor for help in this investigation as well as for help in performing this work.

References

[1] Borre K, Akos D M, Bertelsen N, Rinder P and Jensen S H 2004 Software-Defined GPS and Galileo Receiver: A Single-Frequency Approach. Applied and Numerical Harmonic Analysis (Boston: Birkhauser) 87–108
[2] James B T 2004 Fundamentals of Global Positioning System Receivers: A Software Approach (John Wiley & Sons) 165–190
[3] Kaplan E D and Hegarty C J 2006 Understanding GPS/GNSS: Principles and Applications (Artech House) 153–200
[4] Tsikin I A and Melikhova A P 2017 Direct signal processing for GNSS integrity monitoring (Lecture Notes in Computer Science) 635–643
[5] Tsikin I A and Shcherbinina E A 2018 Algorithms of GNSS signal processing based on the generalized maximum likelihood criterion for attitude determination (25th Saint Petersburg
[6] Rachitskaya A P and Tsikin I A 2018 Gnss integrity monitoring in case of a priori uncertainty about user’s coordinates (IEEE International Conference on Electrical Engineering and Photonics, EExPolytech) 83–87

[7] Betz J W and Kolodziejski K R 2000 Extended Theory of Early-Late Code Tracking for a Bandlimited GPS Receiver 47 (Journal of The Institute of Navigation) 211–226

[8] Betz J W and Kolodziejski K R 2009 Generalized Theory of GPS Code-Tracking Accuracy with an Early-Late Discriminator (IEEE Transactions on Aerospace and Electronic Systems)

[9] Gelgor A, Pavlenko I, Fokin G, Gorlov A, Popov E and Lavrukhin V 2014 LTE base stations localization (Lecture Notes in Computer Science) 191–204

[10] Melikhova A P and Tsikin I A 2018 Optimum Array Processing with Unknown Attitude Parameters for GNSS Anti-Spoofing Integrity Monitoring (41st International Conference on Telecommunications and Signal Processing)

[11] Melikhova A P and Tsikin I A 2018 Decision-making algorithms based on generalized likelihood ratio test for angle-of-arrival GNSS integrity monitoring (25th Saint Petersburg International Conference on Integrated Navigation Systems) 1–5

[12] Tsikin I A and Poklonskaya E S 2017 Accuracy of secondary surveillance radar system remote analysis station (Lecture Notes in Computer Science) 598–606.

[13] Shcherbinina E and Tsikin I 2016 GPS Antenna array calibration for attitude determination based on reference phase difference method (39th International Conference on Telecommunications and Signal Processing) 174–177

[14] Sadovava Y and Gelgor A 2018 Synthesis of signals with a low-level of out-of-band emission and peak-to-average power ratio (Proceedings of the 2018 IEEE International Conference on Electrical Engineering and Photonics, EExPolytech) 103–106