

# Analysis of Real-time Beidou Precise Point Positioning Accuracy of Mobile Phone Terminal

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**Abstract**—With the continuous development of China's Beidou navigation and positioning system (BDS), Beidou wide-area real-time precise positioning system is an important part of Beidou system, meeting the needs of the high-precision location service in various industries of the national economy. Based on the real-time high-precision orbit, clock and ionospheric products provided by Beidou wide-area real-time precise positioning service system, this paper uses mobile phone terminals which support Beidou wide-area real-time precise services to verify and evaluate real-time products accuracy and single frequency precise point positioning (PPP) accuracy. The experimental results show that the horizontal positioning accuracy of the real-time BDS single-frequency PPP of mobile phone terminal is 1 to 3 meters and the vertical positioning accuracy is 1.5 to 3.5 meters under the condition of good observation environment.

**Keywords**—BDS real-time wide-area precise positioning service system; real-time precise point positioning

## I. INTRODUCTION

With the announcement of the Beidou Regional Satellite Navigation and Positioning System (BDS) officially put into operation on December 27, 2012, the positioning, navigation and timing (PNT) service performance provided by the BDS system has basically met or exceeded the design performance index[1-5]. With the development and application of GNSS technology, the wide-area real-time precision positioning system that comprehensively utilizes GNSS technology, information technology and network technology is the development trend of GNSS application field, to meet the demand for high-precision location services[6-8]. In 2014, Beidou high-precision wide-area real-time service system was officially launched as an important part of BDS. Based on real-time data of multiple observation networks in the global and Chinese regions, Beidou wide-area real-time system can be realized. It provides high-precision real-time positioning service in meters, decimeters and centimeters. The system processes precise orbit, clock offset and ionosphere products in real time and broadcasts it to users. Based on ZTE mobile phone, experiments were carried out to analyze the accuracy of real-time single-frequency BDS PPP of the mobile terminal. Based on the mobile terminal that supports real-time precise positioning service, this paper evaluates the positioning accuracy of the mobile terminal through PPP experiment, and then evaluates and analyzes the real-time positioning service.

## II. SINGLE FREQUENCY BDS PPP METHOD

### A. Mathematical Model

The BDS pseudorange and carrier phase observations can be expressed by equation (1) as follows:

$$\begin{aligned}\Delta P_{r,f}^s &= u_r^s \Delta x_r^s + t_r - t_f^s + \beta_{r,f}^s \cdot I_{z,r}^s + \varepsilon_p \\ \Delta L_{r,f}^s &= u_r^s \Delta x_r^s + t_r - t_f^s - \beta_{r,f}^s \cdot I_{z,r}^s - \lambda_f \cdot N_{r,f}^s + \varepsilon_L\end{aligned}\quad (1)$$

In the above formula,  $P$  and  $L$  represent the pseudorange and carrier phase observation,  $r$  is the receiver,  $s$  is the satellite,  $f$  is the frequency,  $\Delta$  is the difference between observed and calculated values, and the error of the phase center and the solid tide are corrected (m);

$u_r^s, \Delta x_r^s, \Delta x_r^s$  is the parameter to be estimated, including the receiver coordinates and the tropospheric delay,  $u_r^s$  is the coefficient of the parameter to be estimated after linearization;

$t_r$  is the receiver clock error,  $t_f^s$  is the satellite clock error;  $I_{z,r}^s$  is the total electron content in the zenith direction,  $\beta_{r,f}^s$  is the ionospheric projection function;  $N_{r,f}^s$  is the integer ambiguity (cycle),  $\lambda_f$  is the wavelength of carrier observation;  $\varepsilon_p$  and  $\varepsilon_L$  represent the carrier and pseudorange observation noise.

The traditional ionospheric-free PPP and the zero-deference, un-combined PPP have their own advantages and disadvantages. Although the ionospheric delay in the ionospheric-free PPP is eliminated by the combination of observations, the combination of the amplified noise is amplified (about 3 times the original observation), and the ionospheric-free PPP function model is only suitable for dual-frequency observation. The information of multi-frequency observations cannot be fully utilized. Single-frequency PPP can make full use of the information of each observation, but the ionospheric delay needs to be estimated, and the number of ambiguity parameters increase.

The PPP stochastic models includes stochastic model of observations and the parameters to be estimated. The stochastic

model of observations gives the statistical properties of the observations by the variance-covariance matrix. The accuracy of the pseudorange and carrier phase observations is different. The two types of observations are considered to be independent of each other. In addition, the elevation angle is usually used to weight these two types of observations. For the traditional ionospheric-free PPP, the stochastic model of the observations needs to establish the corresponding model according to the law of error propagation. The parameters to be estimated for BDS PPP include receiver position, clock error, zenith tropospheric delay, and ionospheric delay parameters. The determination of the receiver position is related to its motion state, and the corresponding process noise is determined according to static and dynamic. Receiver clock and zenith tropospheric delays can be simulated using random walks or first-order Markov processes. The ionospheric delay variation is more complex, and it is necessary to describe the spatiotemporal variation of the ionosphere using a piecewise function and a random walk<sup>[9]</sup>. According to the above BDS PPP mathematical model, PPP settlement can be realized by selecting the appropriate parameter estimation method. In this paper, the square root information filtering solution is selected.

#### B. Real-time Beidou PPP Software Based on Mobile Phone Terminal

The real-time BDS single-frequency PPP software based on mobile phone terminal mainly includes four modules, which are original observation data and navigation ephemeris processing module, precise satellite orbit and clock error and ionospheric products processing module, PPP solution module and a graphical real-time display module. The software structure diagram is shown in Figure 1.

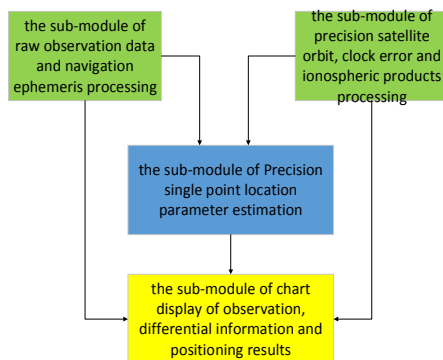


FIGURE I. STRUCTURE DIAGRAM OF REAL-TIME PPP SOFTWARE

The software original observation data and the navigation ephemeris processing module realize serial communication with the Novatel OEM motherboard. The SN or the CSI motherboard receives and parses the original binary data sent by the receiver. It also obtains the pseudorange, carrier phase and broadcast ephemeris data and the data is stored in the storage medium according to the rinex format. Next, log in to the wide-area system server through the GPRS module, receive the precise orbit, clock error and ionospheric correction data through the network, and input them to the PPP solution module, and stored in a storage medium. Then, Obtain various data input by the above module, and perform real-time static or

dynamic precise single point positioning in a non-difference mode.

In the satellite cloud image, the satellite distribution map in the field of view, the distribution of the deleted satellite, the residual map of each satellite pseudorange and phase observations, and the real-time display of the dynamic positioning result in the trajectory window can be displayed in real time motion trajectory (including horizontal and vertical directions). Information such as observation time, station coordinates, and positioning accuracy can be displayed in real time in the station information window.

### III. EXPERIMENTAL RESULTS AND ANALYSIS OF REAL-TIME SINGLE-FREQUENCY BDS PPP PERFORMANCE

Based on ZTE mobile phone, the performance of real-time single-frequency BDS PPP is analyzed. The ZTE mobile phone is shown in Figure 2. ZTE mobile phone and Taidou cooperate to realize the output of single-frequency raw observation data of mobile phone terminal, which makes it possible to realize real-time single-frequency PPP based on mobile phone terminal.



FIGURE II. ZTE MOBILE PHONE TERMINAL

The error corrections and estimation strategies of real-time single-frequency BDS PPP are shown in Table 1.

TABLE I. REAL-TIME SINGLE-FREQUENCY BDS PPP SOLUTION STRATEGY

parameter	Model
observed value	Original carrier and pseudo-range observations
sampling frequency	1s
Elevation mask	7°
PCO/ PCV	model correction PCV is not correct
Earth tides	IERS 2010
Tropospheric delay	Saastamoinen correction model, GMF projection
Ionospheric delay bias	As a prior ionospheric constraint, GIM is used for piecewise estimation of structural parameters (5min) of the ionosphere, and random walk estimation is used for time-varying parameters
Receiver clock error	White noise estimation

#### IV. DYNAMIC SINGLE-FREQUENCY BDS PPP OF MOBILE PHONE TERMINAL

##### A. Analysis of Roof Test Results

The experiment used three mobile phones (#64, #65, #66) and was placed on the top floor of the 15th floor of the Teaching Experimental Building of Wuhan University. The observation environment was good, which is shown in Figure 3.



FIGURE III. TEST ENVIRONMENT

The data sampling interval is 1 s, the cutoff elevation angle is 7 degrees, and the positioning result is compared with the known coordinates of the observation point, and the known coordinates are obtained by the short baseline solution. The positioning error time series is shown in Figure 4.

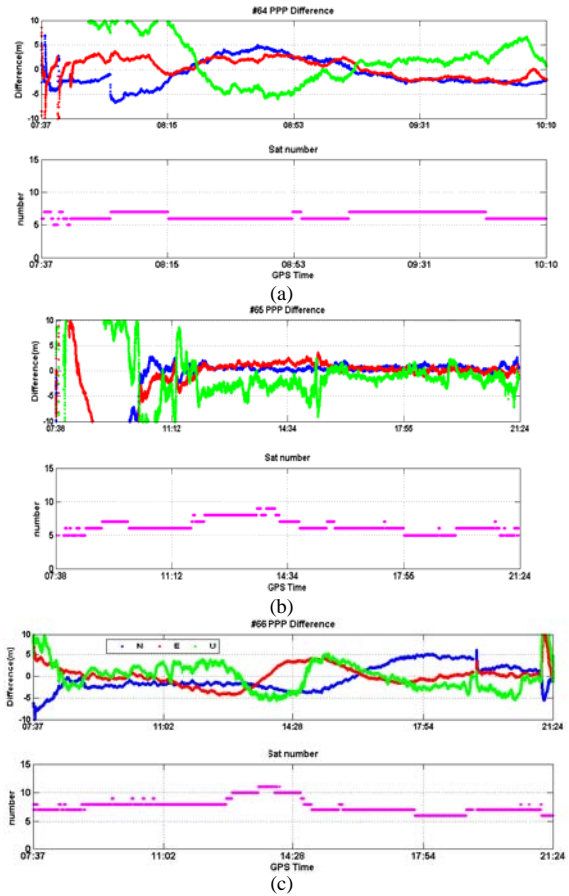


FIGURE IV. TIME SERIES OF PPP POSITIONING ERROR OF THREE MOBILE PHONE ON DECEMBER 30, 2018

Although the three mobile phones are in the same environment, the number of their locked stars is different. Because the BDS GEO satellite is stationary, the convergence speed of the single BDS PPP is relatively slow, and the convergence time are 40 min to 3 hours. Compared with the graphs (a), (b), (c), the number of satellites in the initial stage of (c) is significantly more than that of (a) and (b), the convergence speed is correspondingly faster than that of (a) and (b). So the satellite number affects the convergence speed of the single-frequency BDS PPP. The more satellites there are, the faster the convergence speed will be. The PPP results of the convergence of the three mobile phones are counted, and the RMS is obtained as shown in Table 2.

TABLE II. RMS OF SINGLE-FREQUENCY PPP RESULTS OF MOBILE PHONE TERMINALS

Mobile phone number	RMS (m)		
	N	E	U
#64	2.528	1.897	3.143
#65	0.470	0.762	1.649
#66	2.899	2.193	2.832

The experimental results show that in the case of good observation environment, the horizontal accuracy of single-

frequency BDS PPP of mobile phone terminals is 1 to 3 meters, and the vertical positioning accuracy is 1.5 to 3.5 meters.

### B. Analysis of Square Test Results

The experiment used three mobile phones (#64, #65, #66) to test positioning accuracy on Friendship Square of the Information Department of Wuhan University. The test environment was normal, as shown in Figure 5. The data sampling interval is 1 s, and single-frequency BDS precise single-point positioning is performed, and the positioning result is compared with the known coordinates of the observation point, and the known coordinates are obtained by short-baseline solution. The positioning error time series is shown in Figure 6. As can be seen from Figure 6, although the three mobile phones are in the same environment, their lock stars are different. The #65 mobile phone lock star is better than #64, #66. Compared with Figure 4, the experimental mobile phone has different ability to lock stars in different environments.



FIGURE V. TEST ENVIRONMENT OF FRIENDSHIP SQUARES ON JANUARY 20, 2018

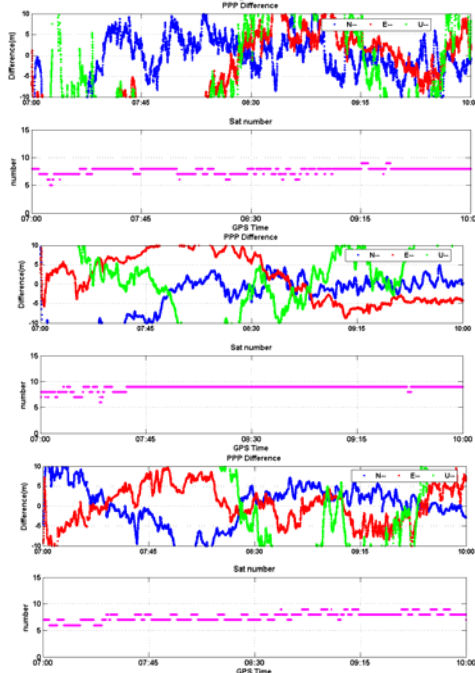


FIGURE VI. TIME SERIES OF PPP POSITIONING ERROR OF SINGLE-FREQUENCY BEIDOU IN THREE MOBILE PHONE ON JANUARY 20, 2018

The statistics of the three mobile phone positioning results are obtained, and the RMS is shown in Table 3. Since there is no obvious convergence process, the data of the full arc segment is counted.

TABLE III. RMS OF SINGLE-FREQUENCY PPP RESULTS OF MOBILE PHONE TERMINALS

Mobile phone number	RMS (m)		
	N	E	U
#64	4.784	7.17	17.161
#65	1.877	6.136	9.894
#66	4.831	4.416	18.838

The experimental results show that in the case of square environment, the horizontal accuracy of single-frequency BDS PPP of mobile phone terminals is 6 to 9 meters, and the vertical positioning accuracy is 10 to 20 meters. Compared with ordinary mobile phone, the positioning accuracy is greatly improved by more than ten meters.

### V. CONCLUSION

This paper first introduces the BDS wide-area real-time precision positioning service system, then introduces the function model and stochastic model of BDS PPP, and describes the real-time BDS PPP software based on mobile terminal, including raw observation data and navigation ephemeris processing module, and precision satellite orbit clock error and ionosphere products processing module, the PPP solution module and the result graphic real-time display module, finally designs a real-time BDS single-frequency PPP experiment based on mobile phone terminal. The experimental results show that in the case of good observation environment, the horizontal accuracy of single-frequency BDS PPP of mobile phone terminals is 1 to 3 meters, and the vertical positioning accuracy is 1.5 to 3.5 meters.

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