Accurate analysis of GPS broadcast ephemeris in the 2036th GPS week

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Abstract. Satellite orbit error is one of main sources in Global Positioning System (GPS) receiver positioning error. Using broadcast ephemeris in navigation message, the receiver can calculate spatial position of GPS satellites, then combine pseudorange measurements and achieve positioning solution. In this work, taking broadcast ephemeris in the 2036th GPS week as an example, orbital position of the satellite with the pseudo-random-noise (PRN) code 4 is calculated. Furthermore, using GPS precision ephemeris as a reference, orbital error of the broadcast ephemeris for the PRN 4 satellite is investigated. The results show that the maximum difference of the satellite in three directions is 36 meters, 57 meters and 39 meters, respectively. The three-dimension distance deviating from precision ephemeris is at most 61 meters. The maximum deviation occurs only during certain time periods in the whole GPS week.

1. Introduction

In the 1970s, the United States Department of Defense (DoD) began to develop the Global Positioning System (GPS). The GPS system was fully built in 1993. Since 1994 it was fully operational and began to provide navigation and positioning services for users around the world. Now it has been widely used in many application fields. The GPS receiver makes use of satellite ephemeris and pseudorange to fix its position. The receiver positioning error is mainly effected by spatial layout of satellite constellation and equivalent ranging error [1, 2]. The spatial layout is usually described by dilution-of-precision (DOP). The smaller the DOP value, the better the spatial layout. The ranging errors between the receiver and the satellite mainly come from satellite orbit, satellite clock, ionospheric and tropospheric effects and receiver measurement noise. These errors are uniformly called the user equivalent ranging error.

This work focuses on satellite orbit error. Satellite ephemeris describing the orbit of a satellite, is a set of orbital parameters and its corrections corresponding to a certain moment. With the ephemeris, someone can calculate position and velocity of specific satellite at any time. The GPS ephemeris includes forecast ephemeris and post-processing ephemeris. They are also called broadcast ephemeris and precise ephemeris, respectively. The broadcast ephemeris is transmitted from the navigation satellite in real time. The precision ephemeris, as its name implies, has a relatively high precision for it is post-processing. Warren and Raquet presented an analysis of the GPS broadcast ephemeris position error on a daily basis from 1993 to 2002 [3]. Here using the broadcast ephemeris of the 2036th GPS week, the broadcast ephemeris error of the satellite with the pseudo-random-noise (PRN) code 4 is analyzed, with reference to the precise ephemeris.
2. Broadcast ephemeris
The broadcast ephemeris typically includes Kepler orbital elements and necessary orbital perturbation correction parameters relative to some reference epoch. The Keplerian elements of the corresponding reference epoch are also called the reference ephemeris. The reference ephemeris only represents the orbital parameters of the satellite in the reference epoch, but under influences of some perturbation functions, actual orbit of the satellite will subsequently deviates from the reference orbit. The degree of deviation depends primarily on the time difference between the observed epoch and the selected reference epoch. If the known satellite reference ephemeris is corrected by the perturbation term of the orbital parameter, the satellite ephemeris of any observed epoch can be extrapolated [1, 4]. Usually the navigation satellite transmits broadcast ephemeris with updating rate of two hours.

3. Precise ephemeris
The precise ephemeris is a satellite ephemeris calculated by some departments in some countries, based on precise observations of GPS satellites obtained by the satellite tracking stations, using a method similar to the method of determining the broadcast ephemeris. It provides satellite orbital information from observation data of some International GNSS (Global Navigation Satellite System) Service (IGS) stations around the world, which is obtained after post-processing. The ephemeris is not transmitted to the receiver through the GPS navigation message, but uses the ground wireless, satellite communication and other means to serve the required users. Data files of precise ephemeris with a certain time interval (usually 15 minutes) can be obtained from the IGS website managed by the Jet Propulsion Laboratory (JPL) of the California Institute of Technology.

4. Accuracy analysis of GPS broadcast ephemeris
In this section, taking the PRN 4 satellite as an example, accuracy of broadcast ephemeris in the 2036th GPS week (from day-of-year 13 to day-of-year 19 in 2019) is analyzed. The precise ephemeris directly gives three-dimensional coordinates of every satellite in the ground-fixed coordinate system at a 15-minute interval. Here we adopt the time interval as calculation step.

Firstly, the orbit position of the PRN 4 satellite is calculated with the broadcast ephemeris, and the orbit error is obtained by subtracting the orbit position obtained from the precise ephemeris. The orbit errors of the PRN 4 satellite are displayed in following Figures. 1-7. The errors in x-, y- and z-direction are given by solid lines of blue, green and red, respectively. Here three-dimension distance deviating from precision ephemeris is also assessed. Statistical results of orbit errors for the satellite during the total 2036th GPS week are list in Table. 1.

[Figure 1: Orbit error of the PRN 4 satellite in day-of-year 13 of 2019]
Figure 2  Orbit error of the PRN 4 satellite in day-of-year 14 of 2019

Figure 3  Orbit error of the PRN 4 satellite in day-of-year 15 of 2019

Figure 4  Orbit error of the PRN 4 satellite in day-of-year 16 of 2019
Figure 5  Orbit error of the PRN 4 satellite in day-of-year 17 of 2019

Figure 6  Orbit error of the PRN 4 satellite in day-of-year 18 of 2019

Figure 7  Orbit error of the PRN 4 satellite in day-of-year 19 of 2019
Table 1. Statistical results of orbit errors for the PRN 4 satellite in the 2036th GPS week.

| Day-of-year in 2019 | Max. error of x-direction (m) | Max. error of y-direction (m) | Max. error of z-direction (m) | Max. distance deviating from precision ephemeris (m) |
|-------------------|------------------------------|-------------------------------|------------------------------|---------------------------------------------------|
| 13                | 12.57                        | 12.91                         | 11.50                        | 14.69                                             |
| 14                | 36.27                        | 37.34                         | 32.94                        | 41.16                                             |
| 15                | 7.77                         | 8.16                          | 6.79                         | 9.25                                              |
| 16                | 5.55                         | 4.80                          | 4.97                         | 6.67                                              |
| 17                | 29.46                        | 56.91                         | 38.68                        | 61.17                                             |
| 18                | 1.61                         | 1.81                          | 1.66                         | 1.93                                              |
| 19                | 1.59                         | 1.56                          | 1.69                         | 2.51                                              |

5. Summary
In this work, taking the GPS PRN 4 satellite as example, accuracy of broadcast ephemeris is evaluated in the 2036th GPS week. Comparing with the precision ephemeris, obvious errors exist in the broadcast ephemeris. Maximum errors in x-, y-, and z-direction reach 36 meters, 57 meters and 39 meters, respectively. Maximum three-dimension distance deviating from the precision ephemeris is about 61 meters. Of course, these errors only take place in several specific time periods of the whole GPS week. It is well-known that orbit error usually appears during renewing broadcast ephemeris files. The errors of satellite orbit and satellite clock should be considered comprehensively. The possible mechanism needs to be studied in the future work. Actually, during high-precision location solution, instead of using the GPS broadcast ephemeris directly, relative measurement and difference techniques are used to eliminate some ranging errors including satellite orbit and satellite clock before the receiver position is fixed.

Acknowledgments
This work was financially supported by National Natural Science Foundation of China (11573041).

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