Varsha H.S Journal of Engineering Research and Application *www.ijera.com*
ISSN: 2248-9622 Vol. 8, Issue 12 (Part -I) Dec 2018, pp 43-46

RESEARCH ARTICLE OPEN ACCESS

Analysis of Pseudo-range Measurements Observed in NavIC Receiver

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ABSTRACT
The Indian Regional Navigation Satellite System (IRNSS), also known as NavIC- Navigation with Indian Constellation provides real time positioning and timing services. The NavIC receivers are placed in different regions. The NavIC receivers provide satellite positions, satellite clock timings and errors, other modelled errors including tropospheric and ionospheric delay, receiver position and clock timings, pseudo range measurements and other information related to both satellite and receiver. In this paper, the pseudo range measurements obtained from the receiver is analyzed and the observations are discussed.

Keywords-IRNSS, pseudo range, NavIC receiver, satellite clock correction, ionosphere delay, troposphere delay, multipath delay, satellite communication.

Date of Submission: 18-12-2018 Date of Acceptance: 31-12-2018

I. INTRODUCTION

All the satellites in the GNSS system have precise Rubidium or Cesium stable atomic clocks. GNSS receivers have crystal oscillator which provides time, which should be synchronized with the onboard atomic clock. But, the GNSS receiver uses economical kind of clock which is not exactly synchronized with the onboard satellite clock. Therefore the clock offset is observed between the onboard satellite and the receiver clock [1]. The distance or range between the satellite and receiver is computed by measuring the time elapsed for a signal to propagate from a satellite to a receiver and multiplying it by the speed of light. This implies that any error in time will be reflected in the computed range. So the receiver clock error should be estimated. Availability, reliability and integrity of IRNSS navigation parameters are affected by satellite clock errors. Hence, for precise navigation applications, satellite clock error needs to be corrected. For precise navigation solution the pseudo range needs to be corrected for the errors like satellite clock error, ionospheric delays, tropospheric delay, multipath delay etc. [2]. The ionosphere and troposphere are not uniform in composition and the refractive index changes all along the path of a signal. Change in signal speed changes the travel time of the signal and, therefore, changes the apparent pseudo range computed.

Satellite Application Centre (SAC), ISRO installed NavIC receiver in the department of Electronics and Communication, Dayananda Sagar College of Engineering, Bengaluru, India. Systematic and routine measurements are being carried out from the network of IRNSS satellites.

II. FACTORS AFFECTING RANGE CALCULATION

The measurement received by the NavIC receiver consists of pseudo range values measured between the satellite position and the receiver position. But these values have multiple errors added due to ionospheric delay, tropospheric delay, multipath delays, satellite clock errors, satellite orbit errors and some unmodeled effects. But, the major factor accounting to errors is the satellite clock error.

A. Satellite Clock Correction

The satellite clock error has a major impact on the pseudo range and is given by the following equation.

$$P_m = \rho + \varepsilon^{Sc} \times C \quad (1)$$

where,
P_m = Measured range (m)
ρ = True range (m)
ε^{Sc} = Satellite clock error (s)

C = Velocity of light (m/s)
From (1) it is evident that satellite clock error of 1 microsecond will lead to approximately 300 m of error in the pseudo range [1].

B. Ionosphere Delay

The ionosphere is the layer of atmosphere between 75 km and 1000 km above the earth. The ionization is caused by the sun radiation and the state of the ionosphere is determined primari1y by the intensity of the solar activity. These ions delay the satellite signals and can cause a significant amount of satellite position error. Ionospheric delay varies with solar activity, time of year, season, time of day and location [4].

C. Tropospheric Delay

The troposphere is the layer of atmosphere closest to the surface of the Earth. Variations in tropospheric delay are caused by the changing humidity, temperature and atmospheric pressure in the troposphere. The signals are also refracted by the lower part of the earth's atmosphere composed of dry gases (mainly N_2 and O_2) and water vapor. Since tropospheric conditions are very similar within a local area, the base station and receivers experience very similar tropospheric delay [4].

D. Multipath Delay

Multipath occurs when a GNSS signal is reflected off an object, such as the wall of a building, to the GNSS antenna. Because the reflected signal travels farther to reach the antenna, the reflected signal arrives at the receiver slightly delayed [5]. This delayed signal can cause the receiver to calculate an incorrect position.

III. PSEUDO RANGE CORRECTION USING RECEIVER DATA

The pseudo range (ρ) values available from the IRNSS receiver are not the correct range measurements. According to the Accord Software &Systems Pvt Ltd. receiver ICD document [6], the ionospheric delay (I_d) and the tropospheric delay(T_d) which are available from the receiver must be subtracted from the pseudo range, and the satellite clock correction (e_{clk}) information must be added to the same. The corrected pseudo range (ρ_c) is given by,

$$\rho_c = \rho - T_d - I_d + e_{clk} \qquad (2)$$

Theoretically, the pseudo range can be calculated using the satellite position (X_{sat}, Y_{sat}, Z_{sat}) and receiver position (X_{stn}, Y_{stn}, Z_{stn}) as shown below,

$$\rho_{th} = \sqrt{(X_{stn} - X_{sat})^2 + (Y_{stn} - Y_{sat})^2 + (Z_{stn} - Z_{sat})^2} \qquad (3)$$

The ρ_c obtained from (1) can be compared with theoretically calculated measurement.

IV. OBSERVATIONS

In this paper, March 11th 2018, March 12th 2018 and March 13th 2018 of IRNSS 1B satellite data is considered for analysis. The pseudo range values along with the ionospheric delay, tropospheric delay and satellite clock corrections with respect to time as obtained from the receiver are tabulated in Table 1.

Table 1: Pseudo-range along with different errors corresponding to the time instant.

TOWC (s)	Week no	PR (m)	Iono Delay (m)	Tropo Delay(m)	Satellite Clock Corrections(m)
0	968	37596847.8	0.651649	3.518669	215471.4807
1	968	37596773.9	0.651639	3.518976	215471.4806
2	968	37596702.9	0.651629	3.519085	215471.4804
3	968	37596626.8	0.651619	3.518886	215471.4803
4	968	37596552.3	0.651609	3.519196	215471.4801
5	968	37596479.5	0.651598	3.518424	215471.48
6	968	37596407.8	0.651588	3.519056	215471.4798

These values are used to calculate the corrected pseudo range as given in (2). The corrected pseudo range value corresponding to the same time instant is shown in Table 2.

Table 2: Corrected pseudo range measurements (m)

TOWC (s)	Week no	PR - I.D - T.D + Sat Clk Correction
0	968	37812315.13
1	968	37812241.2
2	968	37812170.23
3	968	37812094.12
4	968	37812019.59
5	968	37811946.83
6	968	37811875.06

The satellite positions and receiver position for the same epoch is given in Table 3 and 4 respectively. The theoretically calculated pseudo range values using (3) is tabulated in Table 5 along with the corrected pseudo range obtained from the receiver.

Table 3: Satellite position (Xsat, Ysat, Zsat)

TOWC (s)	Sat X Pos (m)	Sat Y Pos (m)	Sat Z Pos (m)
0	20042717.7	32170725.2	-18555635.4
1	20042665.7	32171095.8	-18555060.9
2	20042613.7	32171466.4	-18554486.4
3	20042561.8	32171837.1	-18553911.7
4	20042509.9	32172207.7	-18553336.9
5	20042458.1	32172578.3	-18552762.1
6	20042406.3	32172949	-18552187.1

Table 4: Receiver position (Xstn, Ystn, Zstn)

TOWC (s)	Stn X pos (m)	Stn Y pos (m)	Stn Z pos (m)
0	1339048.05	6072955	1415613.75
1	1339048.12	6072954.78	1415613.68
2	1339047.99	6072955.09	1415613.71
3	1339048.01	6072954.33	1415613.39
4	1339048.17	6072955.73	1415613.39
5	1339048.24	6072954.3	1415613.44
6	1339048.43	6072954.77	1415613.67

Table 5: Pseudo range measurement difference (m)

TOWC (s)	PR-Theoretical	Corrected PR (m)	PR difference (m)
0	37812321.57	37812315.13	6.4380643
1	37812248.29	37812241.2	7.08886636
2	37812174.79	37812170.23	4.56462305
3	37812101.76	37812094.12	7.643145718
4	37812027.34	37812019.59	7.749601826
5	37811954.92	37811946.83	8.093184836
6	37811881.23	37811875.06	6.16953674

It can be observed from Table 5 that there is 4-10 meters difference between theoretical value and observed value. This error might be because of the multipath effects or any other unmodeled delays. This difference in range measurements was observed over 3 hours daily for three days at the same time period.

Figure 1 shows the plot of range differences of 3 days over 1 hour of data. The x-axis is the time period in minutes and the y-axis denotes the error/ difference in pseudo range measurements, measured in meters.

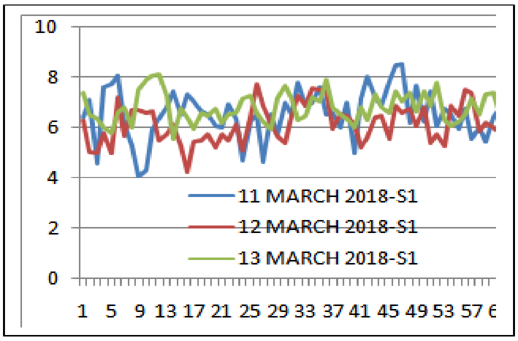

Figure 1: Plot of Pseudo range errors of 3 days over 1 hour.

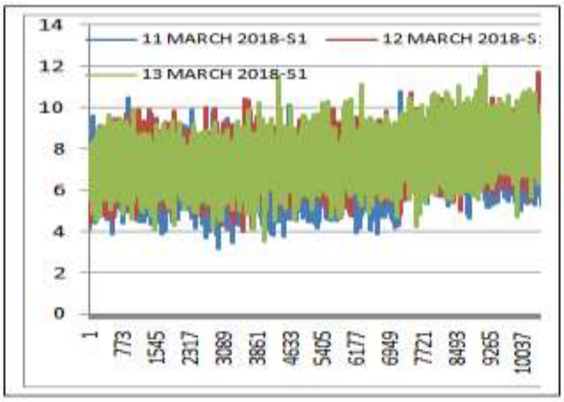

Figure 2: Plot of Pseudo range errors of 3 days over 3 hours.

Figure 2 is the plot of range differences of 3 days over 3 hours of data. The x-axis is the time period in minutes and the y-axis denotes the error/ difference in pseudo range measurements, measured in meters. It can be observed that the pseudo range errors are in the range of 4-10 meters.

The tropospheric delay and ionospheric delay, as explained in section II have little effect on the pseudo range error compared to the satellite clock error. This is evident in Table 1. But, the tropospheric delay and satellite clock error observed are almost in the same range all throughout the day, whereas, ionospheric delay varies with solar activity, time of year, season and time of the day. Ionospheric delay is high in the day time and is at its peak during noon. It gradually reduces during evening and is minimum at the night, in the absence of the sunlight. The figure 3 shows this variation observed over full 24 hours on one day.

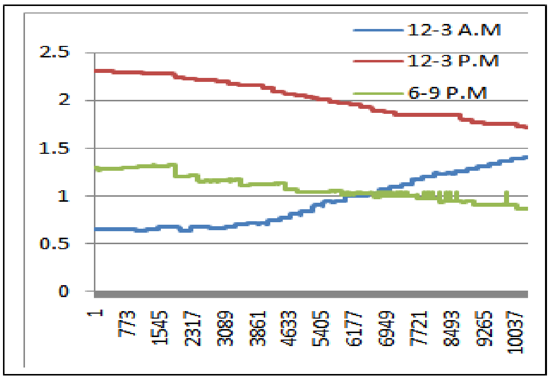

Figure 3: Plot of Ionosphere delay of one full day.

It can be observed from Figure 3 that the mean ionospheric delay from 12 A.M to 3 A.M is 0.94 m, 12 P.M to 3 P.M is 2.01 m and from 3 P.M to 6 P.M is 1.07 m. So, the ionospheric delay is less in the absence of sunlight and high during noon.

V. CONCLUSION

For precise navigation solution the pseudo range needs to be corrected for the errors like satellite clock error, ionospheric delays, tropospheric delay, multipath delay etc. The satellite clock error accounts for the majority of the errors, while the tropospheric and ionospheric delays have less impact on the pseudo range measurement. The mean ionospheric delay of 0.94 m during the night, 2.01 m during the noon and 1.07 m in the evening implies that the delay is less in the absence of sunlight and high during noon. The difference in the pseudo range measured and calculated, and the effect of different delays on the pseudo range measurement observed over 3 days is discussed in section II. Even after applying the corrections using (2), an error of 4-10 meters is observed. This error might be because of the multipath effects or any other unmodeled delays.

ACKNOWLEDGEMENTS

The work undertaken in this paper is supported by SAC/ISRO under NavIC GAGAN utilization program (Project ID : NGP 27), at Space Application Centre, Ahmedabad. Authors wish to acknowledge the support given by SAC/ISRO. Also, the authors would like to thank Mr. Shashank S, Engineer, Accord Software & Systems Pvt Ltd. for his continued support.

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Varsha H.S" Analysis of Pseudo-range Measurements Observed in NavIC Receiver" International Journal of Engineering Research and Applications (IJERA) , vol. 8, no.12, 2018, pp 43-46