Design and Implementation of Dual Frequency, SDCM Corrections for GNSS

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Abstract: Atmospheric Errors causes rapid change in the amplitude and phase of a radio signal as it passes through small-scale plasma density irregularities in the ionosphere and troposphere. These errors reduce accuracy of GLONASS receiver pseudorange and carrier phase measurements. To ensure the accuracy and integrity of user position estimates based upon GLONASS navigation System measurements, System of Differential Correction and Monitoring (SDCM) involve in providing accurate corrections for atmospheric delays. SDCM is an SBAS augmentation system to GLONASS constellation and is used for navigation and precision user position approach. The performance of dual frequency system reflects the elimination of ionosphere errors in terms of integrity. In this paper the dual frequency of SBAS, SDCM corrections for atmospheric errors are simulated and analyzed. The analysis of this paper assures that the user position obtained using SDCM and GLONASS signals errors gives more accurate position, whereas the GLONASS system alone gives a lesser amount of accurate position.

Keywords: System of Differential Correction and Monitoring (SDCM),Fast Correction Messages, Dual Frequency Corrections, Atmospheric Errors, GLONASS.

Introduction

Navigation experts worldwide have been discussing for many years about the concept of one navigational system that is available everywhere on the globe, at all the time with great accuracy, integrity and easy to use, which overcomes the limitations of the existing conventional navigational aids. For the civil aviation community whose integrity requirements for safety - of - life are stringent, GPS/GLONASS constellations alone fail to meet such requirements. Thus, the need for augmenting these constellations arises to meet the required navigation performance for aviation use as navigational system covering various phases of the flight.

The Augmentation systems are the satellites which provide corrections for the navigation systems in terms of accuracy, availability, integrity and reliability. An augmentation system fetches the external information from the navigation satellites, process the data, and add corrections to the error information received from navigation systems (such as ephemeris, clock offsets, atmospheric delays, Multipath) and gives proper measurements to the users.

System of Differential Corrections and Monitoring (SDCM) is a system that supports GLONASS navigation system through the use of additional satellite-broadcast messages. These satellites enhance position accuracy for marine, airborne, terrestrial and space users. SDCM systems consist of several ground stations situated at precisely surveyed locations. The ground stations take measurements of one or more of the GNSS satellites, the satellite signals, or other environmental factors which may impact the signal received by the users. Utilizing these estimations, information messages are made and sent to at least one satellite for broadcast to the end users.

In this paper the user position accuracy of GLONASS navigation system has been enhanced by the use of SDCM messages. The SDCM correction messages add corrections (Satellite clock offset) to GLONASS measurements. The errors occurred from atmosphere can be eliminated by the use of Dual frequency SBAS system. The authors investigated that the performance of dual frequency system reflects the elimination of atmospheric errors rather than using single frequency system for IRNSS constellation.

Error Model

There are various errors that get induced onto the signal during its propagation from satellite to the receiver antenna. In earlier days, the term Selective Availability was introduced by GPS, which adds intentional, time varying errors of up to 100 meters. This is to prevent the host enemies from locating precise position. The first source of error is satellite clock noise, which affects the frequency of satellite clocks, thereby modifying the pseudorange and pseudorange rate measurements of the receiver. Before reaching the receiver antenna, satellite signals travel through the Earth's atmosphere. Two layers of the atmosphere (Ionosphere and Troposphere) introduce error in the receiver range and range rate measurements by changing the signal speed. The errors incurred by the Ionosphere and Troposphere are termed Ionospheric error and Troposphere error, respectively. The next source of error is multipath, which refers to the phenomenon of signals reaching the receiver via multiple paths. This occurs when the signals reach the receiver antenna after getting reflected from nearby structures and is predominant in urban environments.

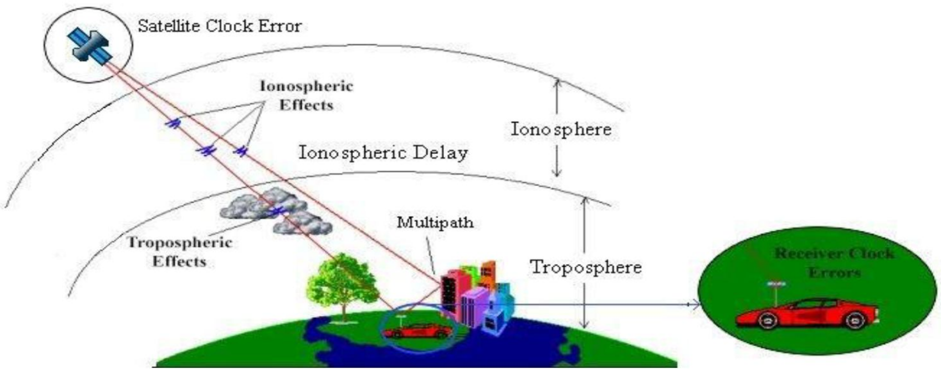

Figure 1: GNSS signal Propagation

The last source of error is receiver clock error, which is introduced by an imperfect (or drifting) receiver clock during signal down conversion. All these error sources are pictorially represented in Figure 1. In order to perform high fidelity simulations, Sim-GUI allows the user to incorporate theses errors in the simulated signals with the help of predefined models.

Simulation Model

Global Navigation Satellite Systems (GNSS) collectively represent navigation satellite constellations of various nations all over the world, including Global Positioning System (GPS) of the US, GLONASS of Russia and Indian Regional Navigation Satellite System (IRNSS) of India. However, many of these applications, in particular those with receivers on-board aircraft and spacecraft, do not always allow the receiver manufacturers to test their equipment in real world conditions.

Figure 2: Accord's GNSS signal generation unit and host computer

A viable solution to this problem is to simulate signals to test GNSS receivers. While simulations cannot offer the full versatility of the real world, it can represent the phenomena to a reasonable degree. This is accomplished by modeling user vehicle and satellite motion, GNSS signal structure, atmospheric and other environmental effects that can affect receiver performance. Thus, simulations can provide a controlled, reliable and repeatable way to test and adequately identify any receiver design limitations. In view of the above, Accord has been developing state-of-the-art GNSS signal simulator. Accord's indigenous GNSS simulator can generate Radio Frequency (RF) signals for GPS, GLONASS, various Satellite-Based Augmentation Systems (SBAS) (all in L1 band) and IRNSS (Standard Positioning Service (SPS) in L5/S band). It also has an intuitive graphical front end through which user can easily configure and track the status of a simulation.

Algorithm for Simulation Set Up

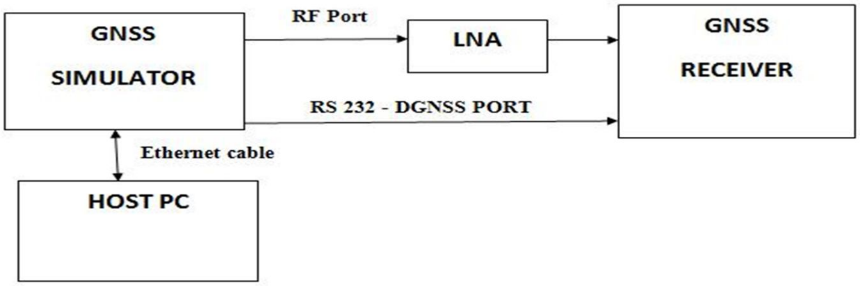

Figure 3: GNSS Simulator test set up with GNSS receivers via RS232 DGNSS port

- The simulator consists of Two Light Emitting Diodes (LED) – power is ON, the Signal Generating Unit (SGU) is powered on and active ON, then the simulation is in progress. These are available in the front panel.
- There are four RF output ports available in the front panel designated as GPS-L1 (port 1), GLONASS-L1 (port 2), IRNSS-L5 & IRNSS-S (port 3) and combined (GPS-L1 + GLONASS-L1 + IRNSS-L5 + IRNSS-S + SBAS) (port 4) RF outputs. Connectors are of 'N' type, receptacle coaxial connector with 50 Ω terminations. Here in this paper port 2, GLONASS – L1 is used for conducting tests.
- Connect the simulator as indicated in test set up and open SimGUI.. Select New Scenario, and provide the required simulation folder and name in Simulation Environment 1. Check for normal mode, if the hardware set up is connected.
- SimGUI will be operating with the default settings unless configured to simulate. The initial settings such as date, time (UTC time) has to be configured. Add Atmospheric Error model and satellite clock noise models.
- Load the almanac data files (YUMA files for IRNSS, GPS and GLONASS). Select the constellations which are required (IRNSS, GPS, GLONASS, SBAS, and DGNSS). Run the simulation and observe that the all receivers are tracking satellites and within 1 minute position should be obtained in receivers.
- Click on view> configuration view> allow minimum of four satellites and click the required constellation. Click on log button in the receiver.
- The receiver log data (NMEA) should have continuous position solution for at least 1 hour. Stop the simulation log and save the file. Click on Simulation Environment 2; select the requited (NAV data and SAT data). The output data files are extracted by clicking on Data Extraction button.
- NMEA extract tool and Matlab analysis tool are used for obtaining receiver plots. NMEA extract tool and Matlab analysis tool are used for obtaining receiver plots.

Methodology

This aim of this section is to achieve the objectives. For SDCM corrections, we take the GLONASS log data file which consists of UTC time, Satellite X, Y, Z positions in ECEF coordinates, Pseudo ranges for all satellites, Delta ranges for duration of 1 hour with 1 second update rate. The user positions are obtained from the data log files in two cases, when satellite clock noise model is disabled and when errors are enabled. As the user position is know, we calculate the user position error occurred in both the cases. By enabling the satellite clock noise model, the user position error will be more compared to user position obtained when satellite clock noise model is disabled.

The aim of SDCM correction messages is to reduce the user position error and get precise position for GLONASS navigation system. GLONASS - L1 signal transmitted by a geostationary SDCM satellite, digital data transmitted at a rate of 250 bit per second are continuously convolution encoded at a code rate of 500 symbols per second. To eliminate satellite clock noise, Fast Correction Messages are generated. There are 4 fast correction message formats each of 250 bits, Message 1 consist correction parameters for satellites 1 to 13. Messages 2 consist of correction information for satellites 14 to 26. 3rd Message consist information for satellite number 27 to 39 and last fast correction message gives correction information for satellite 40 to 51.

The Fast Correction (FC) Message Format is as shown in figure 4. It consists of 8 bit preamble followed by 6 bits message bit identifier. These 6 bits identifies SDCM messages. It had 2 bit IODF-j identifies fast corrections 2, 3, 4 or 5 and 2 bits IODP with tells about PRN mask numbers. There are 212 data bits followed by 24 bits parity check bits. In 212 data bits the first 156 bits (12 bits * 13 satellites) are used for fast correction and other 156 bits (12 bits * 13 satellites) are used for User Differential Range Error (UDRE).

Fast corrections contain the information about correction of measured ranges to navigation satellites. As the user position is known; we calculate the true ranges of each satellite and add corrections to the pseudorange measurements that are obtained

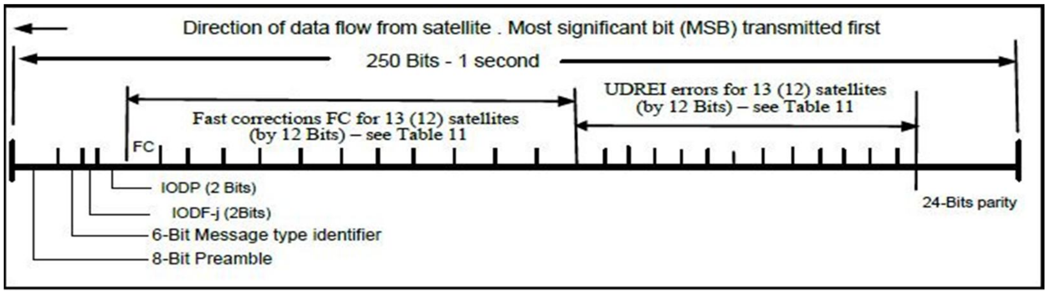

Figure 4: Fast Correction Message Format

from GLONASS log data. Error corrections are subtracted from the User position errors obtained from GLONASS Navigation data which offer the required user position to the end users with huge accuracy.

Results and Discussions

This aim of this section is to analyze and to compare the simulation results obtained for GLONASS signals using User Receiver and GNSS simulator. The signal propagation delay caused by satellite clock noise is now recognized as a major error source for satellite navigation systems. The signal from the GNSS Simulator is given to the User receiver and the data are simulated and analysed for duration of 1 hour.

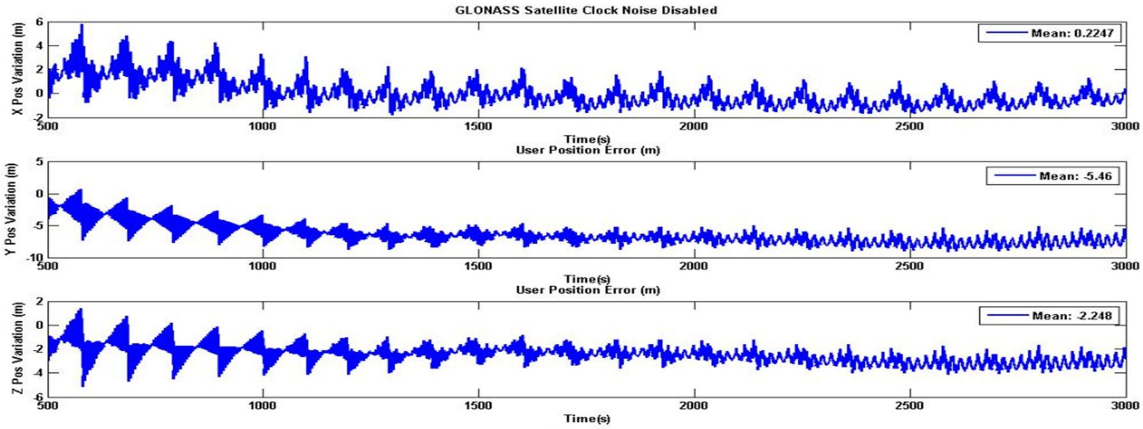

Figure 5: User Position Error plot with satellite clock noise disabled

In figure 5 the user position error is plotted when satellite clock noise model is disabled. The error range varied from 0 to 6 meters. The mean values of user positions errors for X, Y, and Z coordinates are 0.2247 meter, -5.46 meter, and -2.248 meter respectively. The duration of simulation is carried out for 3000 seconds.

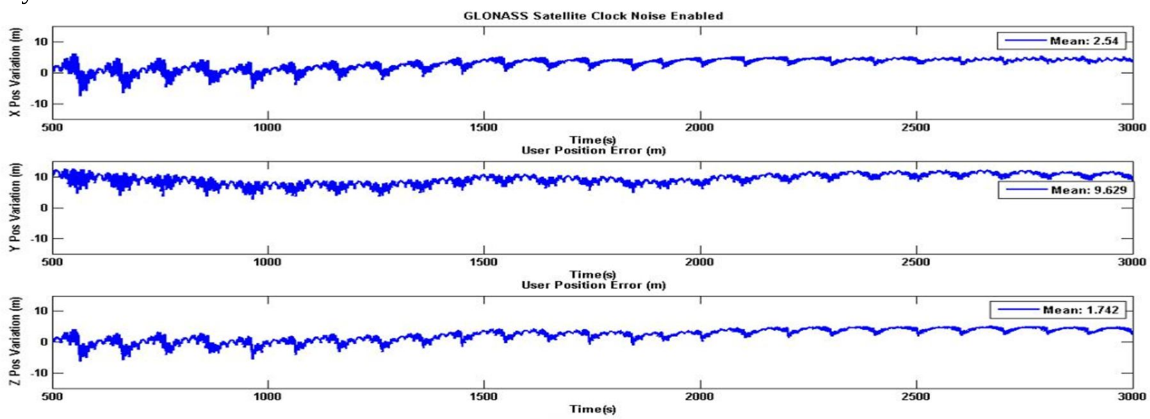

Figure 6: User Position Error plot with satellite clock noise enabled

In figure 6 the user position error is plotted when satellite clock noise model is enabled, where we add satellite clock noise errors to the user position information. The error range varied from 0 to 10 meters. The mean values of user positions errors for X, Y, and Z coordinates are 2.54 meter, 9.629 meter, and 1.742 meter respectively. The duration of simulation is carried out for 3000 seconds.

SDCM fast correction permits compensating fast errors when measuring range to a satellite which arises due to inaccurate predictions of satellite onboard clock offset. This also permits compensating errors introduced by selective availability. Apart from corrections SDCM Message Types 2-5 contain accuracy data. UDRE (User Differential Range Error), which permits to the user to define navigation accuracy.

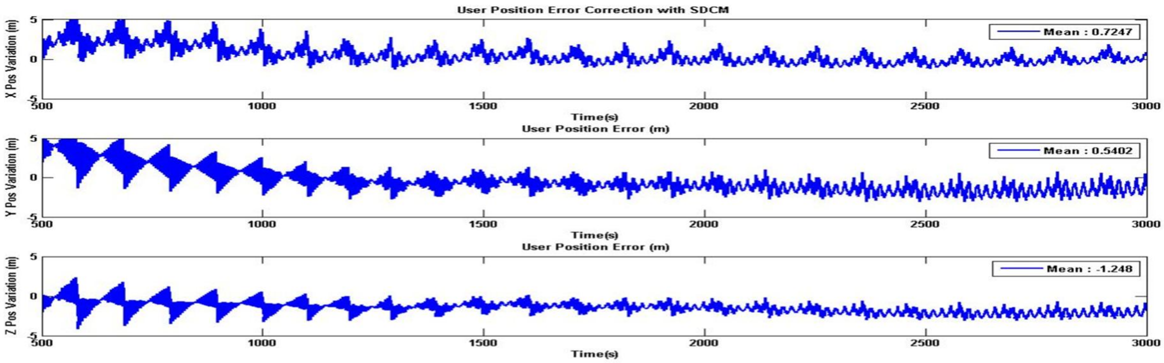

Figure 7: User Position Error correction plot with SDCM

In figure 7 the user position errors are reduced due to SDCM corrections which subtract the satellite clock noise errors from GLONASS navigation information. The error range is varied from 0 to 3 meter. The mean values of user positions errors for X, Y, and Z coordinates are 0.7247 meter, 0.5402 meter, and -1.28 meter respectively. The duration of simulation is carried out for 3000 seconds. From the above plot it can concluded that the satellite clock noise errors are reduced due to use of SDCM fast correction messages. The user position accuracy has been enhanced.

The essential solution for the ionosphere problem is employing dual frequency system. This means the user receiver uses L5 and S frequencies to make a correction against ionospheric delay instead of using SBAS message. In this paper we clarify that the use of dual frequency offers great position accuracy rather than using single frequency for user position estimation.

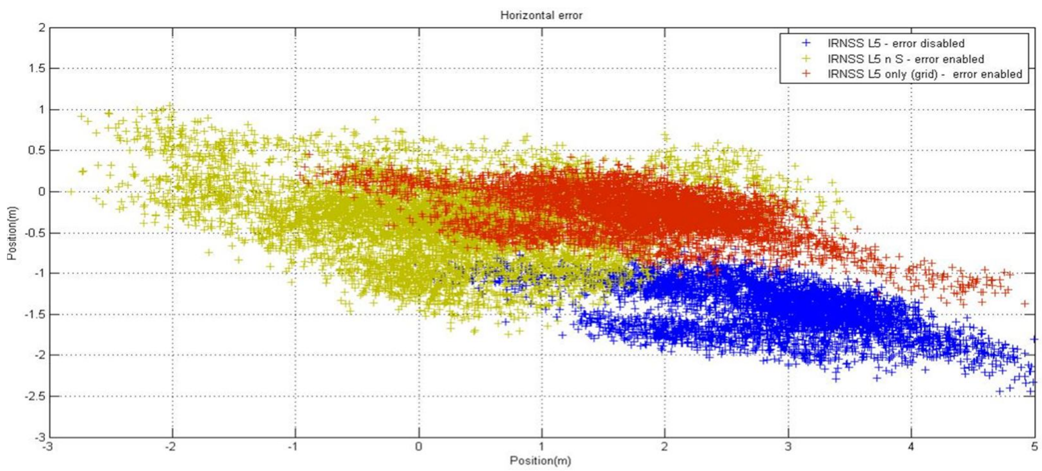

Figure 8: User position accuracy enhancement using Dual frequency for IRNSS constellation

The errors in the live antenna IRNSS signal are unavoidable. The figure 8 shows the position errors occurred by using live antenna signal from the satellites. In this simulation the live antenna signal is given to the user receiver, live data from the satellites are extracted and user position is computed.

The simulated scatter plot of IRNSS constellation with single and dual frequency is as shown. When ionospheric errors are disabled and single frequency L5 is used, the longitude and latitude errors in IRNSS are ~ 5 (Blue scatter plot). By enabling the ionospheric errors with L5 frequency band, the longitude and latitude errors are amplified. The error spread ranges about ~ -1.5 meters to ~ 5 meters in longitude and latitude respectively (red scatter plot). Hence, it is seen that the position error is comparatively minimized by enabling the dual frequency L5 and S frequency bands (green scatter plot). The error spread ranges about ~ -2 meters to ~ 1.5 meters in longitude and latitude respectively. The position accuracy has been enhanced by using dual frequency.

Conclusion

The SDCM corrections for GLONASS system are simulated and analyzed. From the simulation results we have analyzed that user position obtained using SDCM and GLONASS signals gives more accurate position, whereas the GLONASS system alone gives less accurate position. It is also analyzed that the tropospheric and ionospheric errors can be modeled by enabling dual frequency L5 and S in IRNSS constellation which provides fewer errors in user position. The performance of dual frequency system reflects the elimination of ionosphere threat in terms of integrity and accuracy in user position.

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