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Modeling of IRNSS System Time-Offset with Respect to other GNSS

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Abstract

The IRNSS System Time started at 00:00 UT on Sunday August 22nd 1999 (midnight between August 21st and 22nd). At the start epoch, IRNSS system time was ahead of UTC by 13 leap seconds. (i.e. IRNSS time, August 22nd 1999, 00:00:00 corresponds to UTC time August 21st 1999,23:59:47). IRNSS time is a continuous time without leap second corrections determined by the IRNSS System Precise Timing Facility (IRNPT) with an ensemble of Caesium and Hydrogen maser standard atomic clocks.Combining of multi GNSS satellites provides very significant advantages a) paves the way for computing the user position with increased number of satellites. b) Reduced horizontal and vertical Dilution of Precision (DOP) factors. And c) Decreased occupation time which means faster positioning results.This paper presents the 1.IRNSS time offset generation with respect to other GNSS timescales such as GPS, GLONASS system and traceability to UTC,UTC(NPLI)/UTC(K) 2.Validation of predicted time offsets with actual offsets.3.The IRNSS time offsets are derived from GNSS navigation message using UTC offsets to validate the predicted IRNSS time offsets. IRNSS times offset from GNSS are broadcasted in the form of coefficients in one of the IRNSS navigation messages. This broadcast message also allows the user to recover UTC and UTC (NPLI)/UTC(K) time for precise timings.

Keywords: IRNSS, IRNSS Time offsets, IRNWT, UTC, UTC (NPLI) and GNSS

Disclaimer:

This paper does not declare/claim the proposed options are the actual design of new IRNSS service or modifications to existing IRNSS restricted service. The proposed options are part of analysis studies and are adaptable solely by the discretion of program management office of IRNSS, ISRO.

Introduction of IRNSS

Indian Regional Navigational Satellite System (IRNSS) envisages establishment of regional navigational satellite system using a combination of GEO and GSO spacecrafts. The IRNSS system provides navigation solution all time, all weather, anywhere within India and a region extending about 1500 km around India, expected to provide position accuracy better than 20m(95%). The IRNSS system [1] mainly consists of three segments namely: 1) Space Segment, 2) Ground Segment and 3) User Segment. The IRNSS space segment consists of 7 satellites (3 GEO and 4 GSO). The three GEOs will be located at 32.5° E, 83°E and 131.5° E and the four GSOs have their longitude crossings 55° E and 111.75° E (two in each plane). IRNSS satellites have of payloads for navigation broadcast and signal ranging. The payload will transmit the ranging code with navigation data modulated on it. The ground segment is responsible for maintenance and operation of the IRNSS constellation. The ground segment comprises of: 1) IRNSS TTC Stations (IRTTC), 2) IRNSS Spacecraft Control Facility (IRSCF), 3) IRNSS Navigation Centre (INC), 4) IRNSS Range and Integrity Monitoring Stations (IRIMS), 5) IRNSS System Precise Timing Facility (IRNPT), 6) IRNSS CDMA Ranging Stations (IRCDR), 7) IRNSS Laser Ranging Station (IRLRS) and 8) IRNSS Data Communication Network (IRDCN). The user segment mainly consists of: 1) Single frequency IRNSS receiver capable of receiving SPS signal at L5 or S band frequency and 2) A dual frequency IRNSS receiver capable of receiving both frequencies (RS/SPS).

RNSS System Time Overview

The IRNSS System Time started at 00:00 UT on Sunday August 22nd 1999 (midnight between August 21st and 22nd). At the start epoch, IRNSS system time was ahead of UTC by 13 leap seconds.(i.e. IRNSS time, August 22nd 1999, 00:00:00 corresponds to UTC time August 21st 1999, 23:59:47). IRNSS time is a continuous time without leap second corrections determined by the IRNSS System Precise Timing Facility (IRNPT) with an ensemble of Caesium and Hydrogen maser standard atomic clocks, which is steered to Coordinated Universal time (UTC).IRNPT will be provided as a time reference for orbit determination and clock bias computation process. IRNPT will ensure stability and accuracy of the resulting time scale. The ground reference time system for IRNSS, which shall generate IRNSS System Precise Time (IRNPT), has two primary functions:

Navigation Timekeeping: This function is to support the navigation mission and is needed for orbit determination and time synchronization (OD &TS) of the IRNSS constellation.

Metrological Timekeeping: This function is to steer IRNPT towards International Atomic Time (TAI)

IRNPT provides the IRNSS time offsets between UTC time and UTC (NPLI)/UTC(K) {UTC time derived at National Physics Laboratory of India}.This facility also derives the IRNSS time offsets with respect to GNSS timescales such as GPS and GLONASS for every five minutes and stores. IRNPT has two timescales generated in parallel, one is primary and other one is working in hot redundancy. The time offsets will be generated to the primary timescale and uplinked to IRNSS satellites in one of the navigation messages, Message Type 26.

Interoperability

The interoperability of any two satellite navigation systems shall be assured by, among other measures, broadcasting the precise, actual difference between the two system times, such as Galileo System Time (GST) and GPS Time (GPST) and IRNSS System Precise Time (IRNPT).The broadcast of the navigation satellites will improve the interoperability. In poor visibility conditions users may experience limited satellite visibility of GPS or IRNSS. So in these situations mixed combination of measurements will improve the satellite availability, reduces the horizontal and vertical dilution of precision (DOP) so the user can compute his position even in case of poor limited visibility of any satellite based navigation system, utilizing all in view solution would provide the best solution fix. The key to this solution is through precise time solution of the time differences between the two systems such that the measurements from multiple GNSS systems could be used for user position estimation. This paper discusses in detail modeling of time difference between IRNSS and other GNSS systems and broadcast of the same to the IRNSS users through broadcast messages.

Atomic clock ensemble

One method of defining time is by counting periodic events (events theoretically regarded to occur at regular intervals). Atomic time is defined by measuring the periods of the electromagnetic wave absorbed or emitted by a specific atom under given conditions .Atomic time, used to define the second, is the most stable time scale currently available, and forms the basis of global standard time. Actual atomic clocks fluctuate from the ideal theoretical state, and this fluctuation influences the output signal. These fluctuations results in clock errors.

To indicate the "absolute" magnitude of clock "error" it is necessary to introduce the notion of "perfect" or "true" time. Hence it is possible to "measure" clock error as an instantaneous "offset" from the perfect time scale. Over the time the atomic clock oscillator changes will be seen as frequency change. The frequency change is referenced as Frequency aging due to internal changes in the oscillator. This measure does not consider external forces, such as environmental conditions, power fluctuations or vibrations. Frequency drift represents the combined effect of aging and external factors specific to an application. So the standard behavior of an atomic clock can be represented as clock bias (phase offset), clock drift (frequency aging) and clock drift rate (frequency drift).The standard model for clock error is the combination of bias, drift and drift rate, which shows the quadratic pattern in nature.

Any navigation satellite system relies on a highly stable and reliable system time that has to meet high-performance requirements to enable navigation services suitable for navigation and timing communities. The main purpose of system time is to provide a stable reference for precise prediction of satellite clocks. In general, there are two approaches to establish system time that meet requirements of navigation and time services. The first approach, called the Master Clock, is to establish the system time using a high-quality atomic clock e.g. an active hydrogen maser (AHM). Its physical output defines system time. However, implementing system time by a hardware clock creates a single point of failure, since any master clock error like frequency or phase jumps, affects the system time.

The second approach is using an ensemble time algorithm to establish system time. Such algorithms estimate time offsets of every atomic clock in the timing facility with respect to a “paper” system time produced by the algorithm. In this approach, there is no physical representation and system time is equal to a weighted average of all atomic clocks. The IRNSS system time is generated with an ensemble of cesium and hydrogen maser standard atomic clocks.

Irnss time offsets generation

IRNSS navigation parameters generation and uplinking to the satellites is one of the main activities in IRNSS system. These navigation parameters are the primary input to the user for arriving at the position solution and they mainly consist of orbital parameters, clock and other need based parameters. IRNSS time offsets are broadcasted to the IRNSS navigation users through one of its broadcast message type, i.e. Message Type 26[Ref 2]. IRNSS time-offsets generation is one of the main functions in navigation parameters generation system to estimate IRNSS time-offsets with respect to other GNSS system times such as GPS and GLONASS.

IRNPT system provides the IRNSS time offsets as phase differences w.r.t GPS, GLONASS at regular intervals. IRNPT system time is maintained w.r.t UTC through UTC(NPLI)/UTC(K). A series of common view time transfer activities are carried out on regular basis with NPLI in order to maintain the time w.r.t UTC (BIPM).The following parameters are generated on a daily basis and are uplinked to the IRNSS spacecrafts to be used by the user for Interoperability and time-traceability.

IRNSS time offsets w.r.t GNSS (GPS & GLONASS)

Generation process of IRNSS time offset parameters with respect to GNSS is shown in the following figure1.

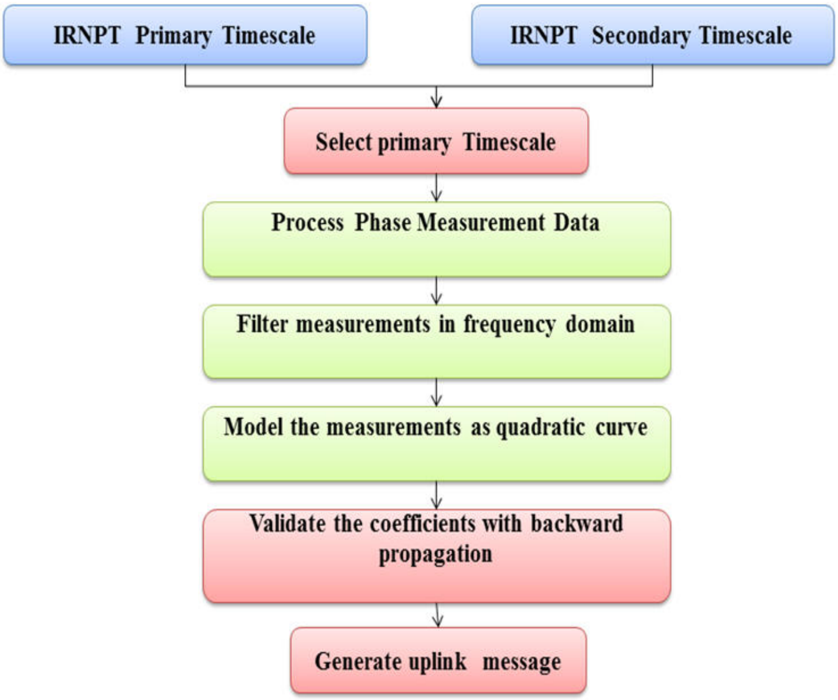

Figure 1: IRNSSTime-Offsets Generation

Irnss time offsets modelling

Methodology

The IRNSS time offsets with respect to GNSS have to be predicted and provide to the user. The clock offset behaviour can be modelled as Bias, Drift, and Drift-Rate. The modelled coefficients can be predicted to the future with an average of one day validity period. Stable clock offset behaviour will be in quadratic manner, which can be captured in bias, drift and drift-rate for ease of application in user time algorithm.

Measurements processing:

The IRNPT provided offsets data is raw data, which is affected by the system noise and the unwanted frequencies. A Fast Fourier Transformation (FFT) is applied to the past good amount of measurements and it filters the unwanted frequencies in the measurements. The filtered data will be processed for smoothing to remove noise. The processed phase measurements are modelled as Bias (A_0), Drift (A_1) and Drift rate (A_2) coefficients. The predicted coefficients for next day with the validity period of 24 hours are uplinked to the IRNSS satellites.

IRNSS Time offsets modeling

The IRNSS time offsets quadratic behaviour is modelled as bias drift and drift rate. The modelling equation is provided as follows

$X(t)=A_0+A_1*t+A_2*t^2$

Where X(t) IRNSS-GNSS offset at ‘t’ time

A_0,A_1 and A_2 are bias, drift and drift-rate respectively.

A_0,A_1 and A_2 are bias, drift and drift-rate respectively.

Irnss broadcast message type 26

Message type 26[2] is one of the IRNSS navigation messages, which provides the IRNSS time offset w.r.t UTC, UTC(NPLI) and other GNSS like GPS,GLONASS,GALILEO etc. The following mentioned parameters are included as part of message type 26.

1) Bias coefficient of IRNSS time scale relative to UTC(NPLI)/GNSS time scale (A_0)
2) Drift coefficient of IRNSS time scale relative to UTC(NPLI)/GNSS time scale (A_1)
3) Drift rate correction coefficient of IRNSS time scale relative of UTC(NPLI)/GNSS timescale(A_2)
4) Time data reference time of week(tot)
5) Time data reference week number(WN_{ot})
6) GNSS type id(GNSSID)

IRNSS time can be related to GPS, GLONASS, GALILEO and UTC (NPLI) using the above parameters GNSSID identifies the GNSS for which the time offsets w.r.t IRNSS are provided in the message type 26. The mapping between GNSSID and GNSS is provided below.

Table 1 GNSSID to GNSS Mapping

GNSSID	GNSS
0	GPS
1	GALILEO
2	GLONASS
7	UTC(NPLI)
3-6	Reserved

The reader is referred to [2] for more details on message type 26.

Summary

The methodology of modeling IRNSS time offsets coefficients with respect to other GNSS (GPS&GLONASS) for interoperability purpose is presented in the paper and also shown the predicted offsets error with the current day's actual offsets. The raw offset data from IRNPT is affected by system noise and unwanted frequencies and the same is processed to get precise offsets. The prediction error of time offsets in normal scenarios is presented here. IRNSS Navigation message type 26 broadcast provides the IRNSS-GNSS Time-offsets in the form of Bias, Drift &Drift rate coefficients and the results are validated regularly. The model represents the time offsets with regard precision. The same methodology for computing other GNSS offsets such as IRNSS-GALELIO and IRNSS-COMPASS etc. will be adopted in future and those coefficients will be broadcasted as part of message type 26.

Acknowledgement

I would like to thank Mr. MV.Kamat for guiding me in the data processing in frequency domain.

References

[1] Indian Regional Navigation Satellite system Navigation Software Design Document, ISRO-ISAC-IRNSS-RR-0900.
[2] IRNSS SIS ICD FOR STANDARD POSITIONING SERVICE VERSION 1.0,ISRO-IRNSS-ICD-SPS-1.0,June-2014.
[3] ICD for IRNWT and Navigation Software, Feb 2013.

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Results

As mentioned in this paper the IRNSS time offsets w.r.t GNSS are modeled as Bias, Drift and Drift rate coefficients. The results for different day's combination are presented here as follows.

The following figures show the raw measurements and the frequency filtered measurements for GPS and GLONASS for different days.

The figure 1 below shows the IRNSS-GPS raw offset filtered in frequency domain from 19/02/2014 to 28/02/2014.

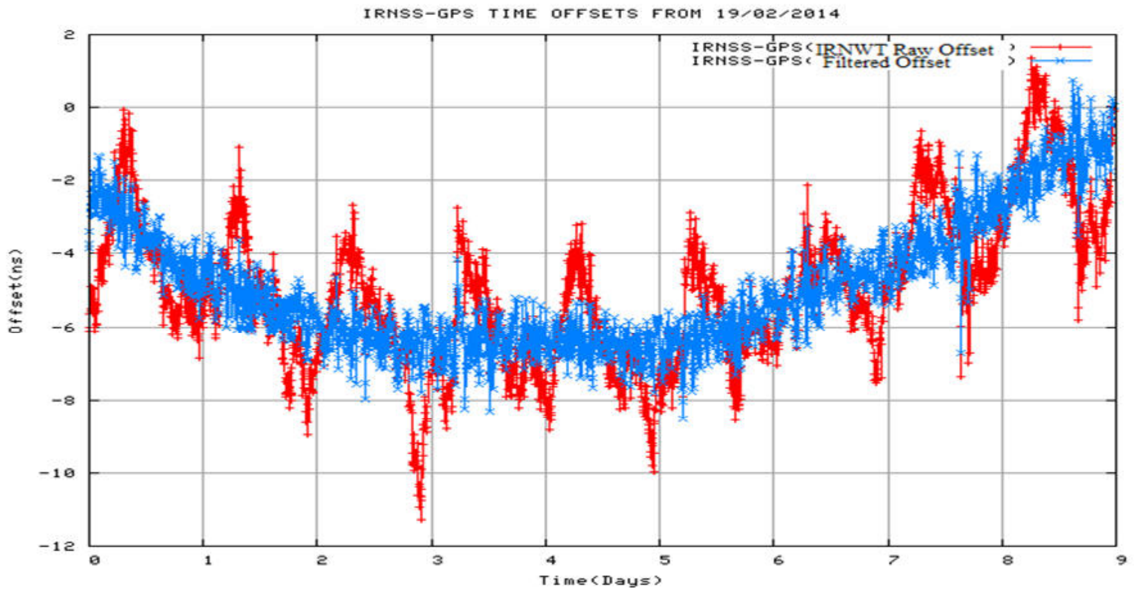

Figure 5 IRNSS-GPS Time offset data from 19/02/2014

The figure 2 below shows the IRNSS-GPS raw offset filtered in frequency domain from 07/04/2014 to 17/04/2014.

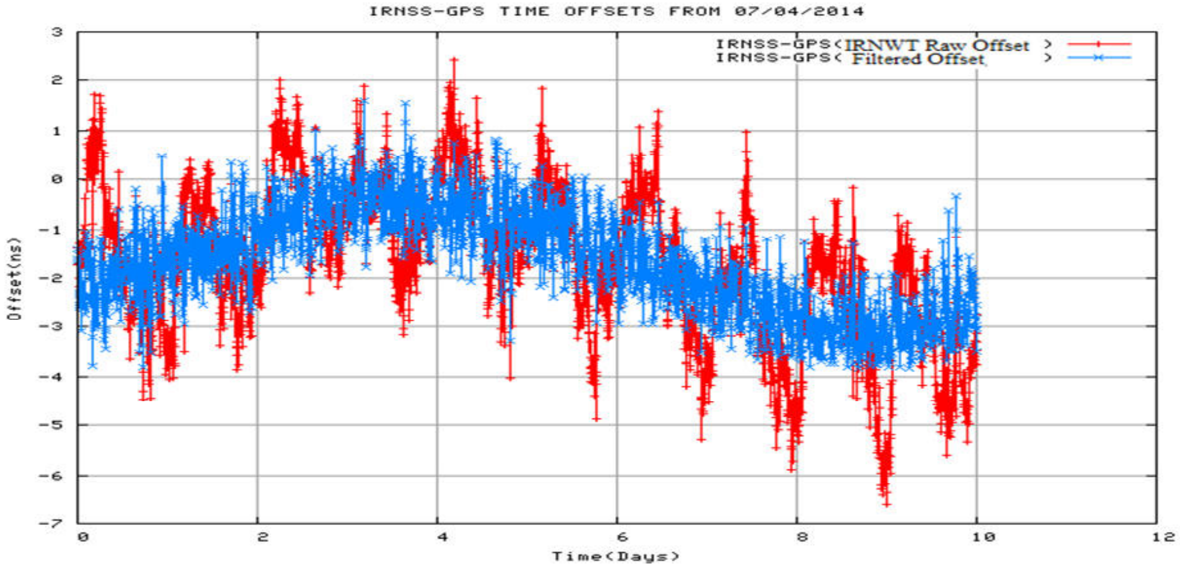

Figure 6 IRNSS-GPS Time offset data from 07/04/2014

The figure 3 below shows the IRNSS-GLONASS raw offsets filtered in frequency domain from 21/03/2014 to 31/03/2014.

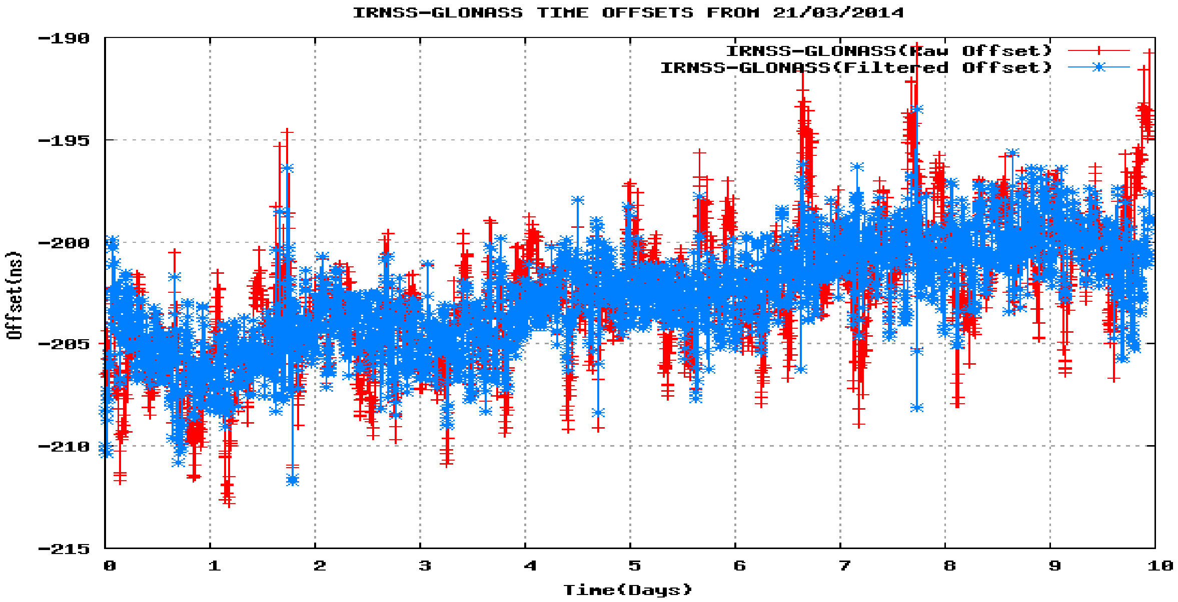

Figure 7 IRNSS-GLONASS Time offset data from 21/03/2014

The filtered data for three days was selected for generating the bias, drift and drift rate coefficients. The post fit measurements were created by propagating the generated coefficients. The below figures show the post fit offsets against input filtered data used for modeling.

The figure 4 below shows the fitting of IRNSS-GPS filtered offsets as quadratic form to model bias drift and drift rate coefficients. The data chosen is from 19/02/2014.

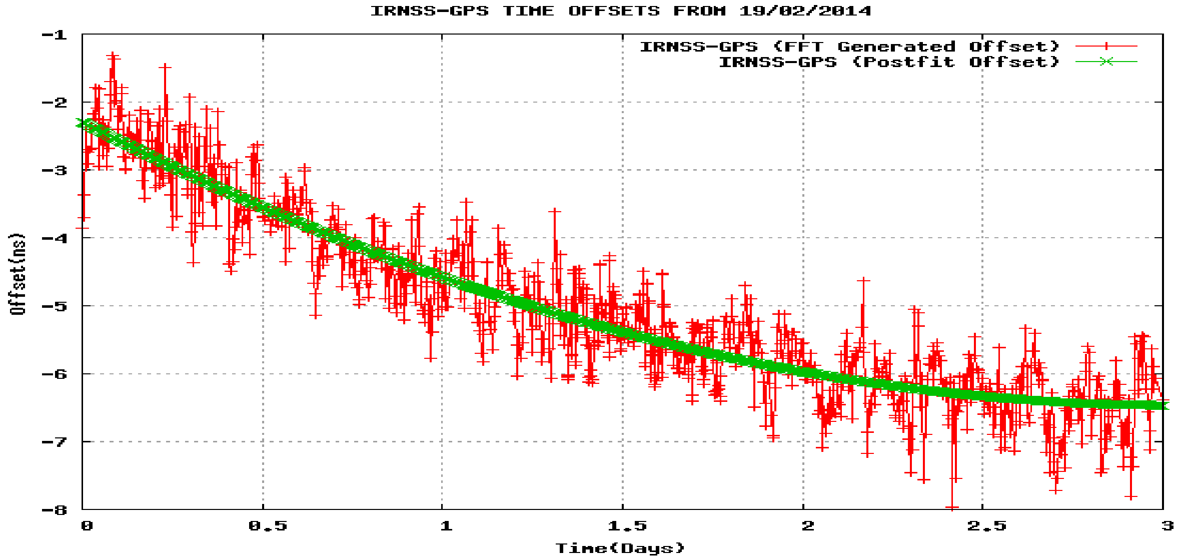

Figure 8 IRNSS-GPS Post fit Offsets Vs Filtered Offsets from 19/02/2014

The figure 5 below shows the fitting of IRNSS-GPS filtered offsets as quadratic form to model bias drift and drift rate coefficients. The data chosen is from 7/04/2014.

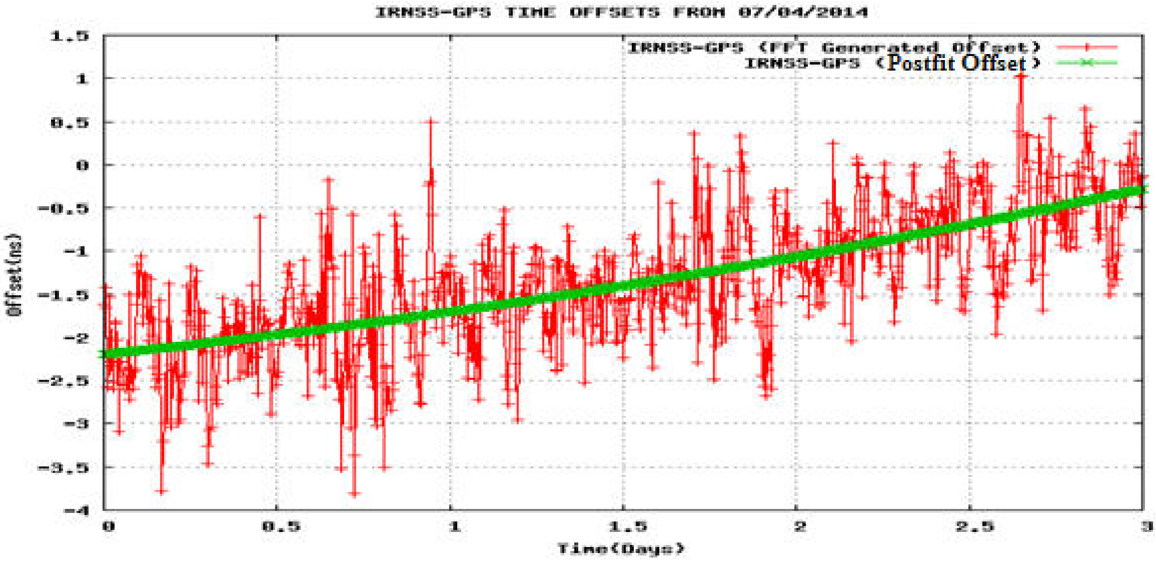

Figure 9 IRNSS-GPS Post fit Offsets Vs Filtered Offsets from 07/04/2014

The following plots show the prediction error. The predicted offset is compared with the current day raw offset from IRNPT and plotted the prediction error as follows.
The prediction error for IRNSS-GPS timeoffsets on 22/02/2014 is given in figure 6 below.

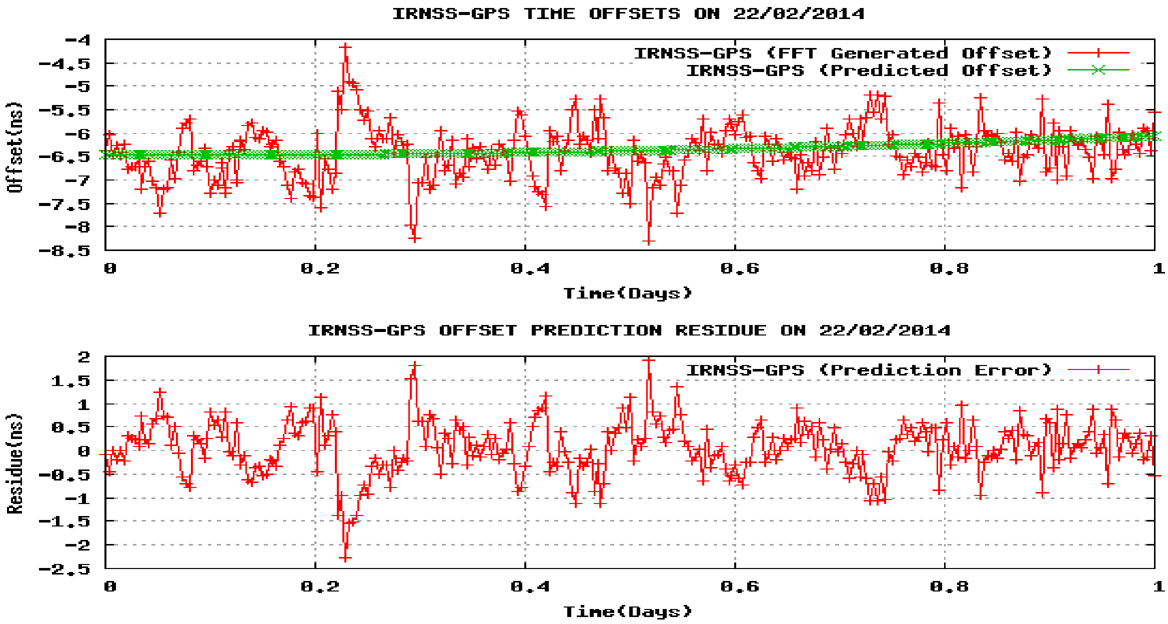

Figure 6 IRNSS-GPS residual error with the predicted Offset on 22/02/2014

The mean and standard deviations of the prediction error in the above figure 6 are 0.062ns and 0.56ns respectively.
The prediction error for IRNSS-GPS timeoffsets on 10/04/2014 is given in figure 7 below.

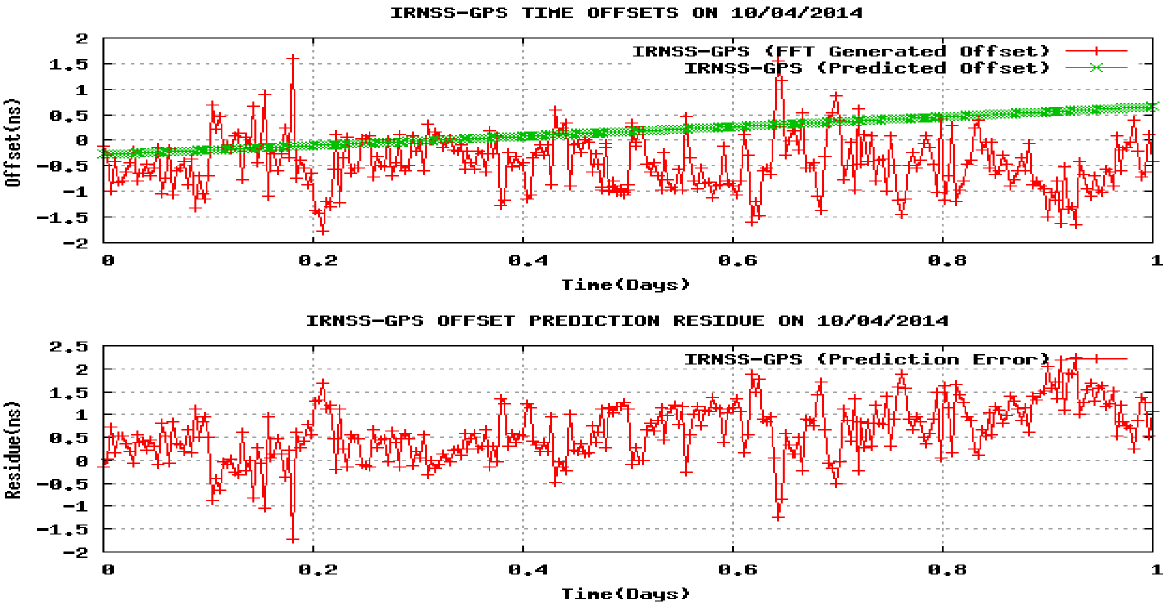

Figure 7 IRNSS-GPS residual error with the predicted Offset on 10/04/2014

The mean and standard deviations of the prediction error in the above figure 7 are 0.62ns and 0.61ns respectively.

The same filtering methodlogy (FFT) is applied to IRNSS-GLONASS offsets and computed theprediction error for on 24/03/2014 as shown in in figure 8 below.

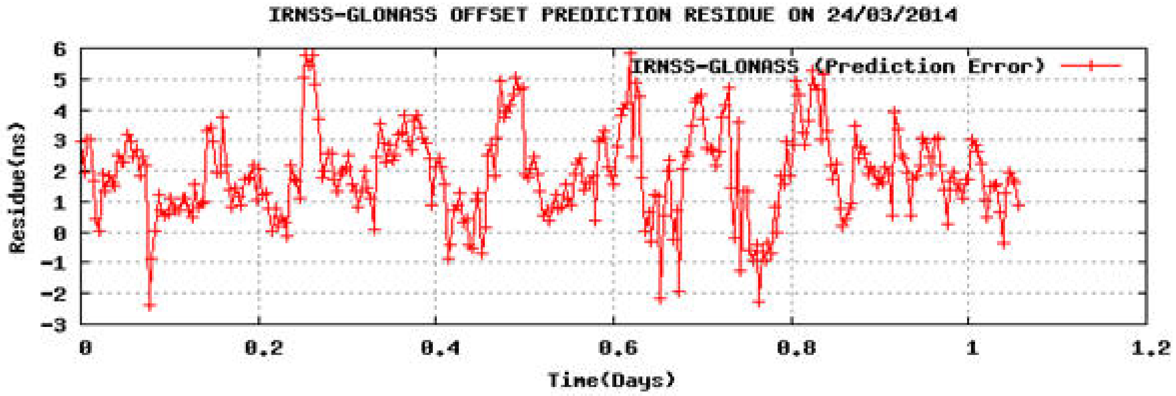

Figure 8 IRNSS-GLONASS residual error with the predicted Offset on 10/04/2014

The mean and standard deviations of the prediction error in the above figure 8 are 0.62ns and 0.61ns respectively.

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