ISSN 2347 - 3983

International Journal of Emerging Trends in Engineering Research (IJETER), Vol. 3 No.6, Pages : 280 - 287 (2015)
Special Issue of NCTET 2K15 - Held on June 13, 2015 in SV College of Engineering, Tirupati
http://warse.org/IJETER/static/pdf/Issue/NCTET2015sp54.pdf

Handling the Biases for Improved Triple-Frequency Carrier-Phase Ambiguity Resolution PPP Convergence for GNSS

Addanki Gayatri [1], Dr.P.V.N.Reddy [2], A. Hazarathaiah[3].
[1] PG Scholar, ECE department, Sri Venkateswara Engineering College for Women, Tirupati, India
Email: gayatri.a1@svcolleges.edu.in
[2]Professor, principal, Sri Venkateswara Engineering College for Women, Tirupati, India
Email: principal_svew@svcolleges.edu.in
[3]Professor, ECE department, Sri Venkateswara Engineering College for Women, Tirupati, India
Email: hazarath.a@svcolleges.edu.in

ABSTRACT

Precise point positioning (PPP) can be considered a viable tool in the kitbag of GPS positioning techniques. One precision aspect of PPP is its use of carrier-phase measurements rather than just pseudoranges. But there is a catch. Often many epochs of measurements are needed for a position solution to converge to a sufficiently high accuracy. In this paper, we look at how measurements are being used from three satellite frequencies rather than just two which can help.

Key words: Precise point positioning (PPP), GPS, carrier-phase measurements.

1. INTRODUCTION

This acronym remains for exact point situating and, in spite of the fact that the method is still being developed; it has advanced to a phase where it can be viewed as another reasonable device in the kitbag of GPS situating systems. It is presently bolstered by various collector producers and a few free online PPP handling administrations. All things considered, doesn't any sort of situating with GPS give you an exact point position including that from a handheld collector. They pivotal word here is exact.

The utilization of the word exact, in the setting of GPS situating, for the most part means getting positional data with accuracy and exactness superior to anything that managed by the utilization of L1 C/A-code pseudorange estimations and the information gave in the show route messages from the satellites. An ordinarily little change in accuracy and exactness can be had by utilizing pseudoranges decided from the L2 recurrence notwithstanding L1. This allows the ongoing revision for the annoying impact of the ionosphere. Such a change in situating is typified in the refinement between the two authority GPS levels of administration: the Standard Positioning Service gave through the L1 C/A-code and the Precise Positioning Service accommodated "approved" users, which obliges the utilization of the scrambled P-code on both the L1 and L2 frequencies.

Common GPS users will have entry to a comparative level of administration once an adequate number of satellites transmitting the L2 Civil (L2C) code are in circle. This ability just give meter-level precision. The PPP procedure can show improvement over this.

It can do as such on account of two extra accuracy parts of the system. The primary is the utilization of more exact (and, once more, precise) depictions of the orbits of the satellites and the behaviour of their atomic clocks than those included in the navigation messages.Such information is given, for instance, by the International GNSS Service (IGS) through its worldwide following system and examination focuses. These so-called precise products are typically used to process receiver data after collection in a post-processing mode, although real-time correction streams are now being provided by the IGS and some commercial entities.

Presently, it’s actual that a user can get high accuracy and exactness in GPS situating utilizing the differential procedure where information from one or more base or reference stations is consolidated with information from the user collector. Notwithstanding, by utilizing exact items and an exceptionally careful model of the GPS observables, the PPP method gets rid of the prerequisite for a straightforwardly got to base station.

The other exactness part of PPP is its utilization of bearer phase estimations instead of just pseudoranges. Bearer phase estimations have an exactness on the request of two extents (a component of 100) superior to anything that of pseudoranges. But there is a catch to the utilization of transporter phase estimations: they are vague by a whole number numerous of one cycle. Preparing calculations must resolve the estimation of this ambiguity and preferably alter it at its right whole number quality. But, it is hard to do this quickly, and frequently numerous ages of estimations are required for a position answer for unite to an adequately high exactness, say superior to anything 10 centimeters. Analysts are effectively taking a shot at decreasing the merging time; we take a gander at how utilizing estimations from three satellite frequencies as opposed to only two can offer assistance.

The rest of this paper is organized as follows. In Section 2 we review the structure of the measurement given by GPS. After that, in Section 3 we discuss the LAMBDA method. In Section 4 we present the basic idea and the overall algorithm. In Section 5 we give the simulation results. Section 6 concludes this paper.

2. SYSTEM MODEL

While bearer phase estimations commonly have low commotion contrasted with pseudorange (code) estimations. They have inborn whole number cycle ambiguity: the transporter phase, translated as reach estimation, is ambiguous by any number of cycles. The whole number vagueness settling is currently routinely connected to undifferenced GPS carrier-phase measurements [1-4] to achieve precise positioning. A few executions are even accessible progressively. This assumed to be exact point situating (PPP) procedure grants ambiguity determination at the centimeter level.

With the new modernized satellites' capacities, performing PPP with triple-recurrence estimations will be conceivable and, subsequently, the current double recurrence detailing won't be clearly related to. There is additionally a requirement for a summed up definition of phase-biass for Radio Technical Commission for Maritime Services (RTCM) State Space Representation (SSR) needs. In this RTCM structure, the meaning of a standard is essential to permit interoperability between the two segments of a situating framework: the system side and the user side.

A. Traditional Formulation

In this area, we audit the definition of the perception comparisons. We will utilize the accompanying constants in the mathematical statements

$$\gamma = \frac{f_1^2}{f_2^2},\ \lambda_1 = \frac{c}{f_1},\ \lambda_2 = \frac{c}{f_2} \qquad (1)$$

Where f_1 and f_2 are the two primary frequencies transmitted by all GPS satellites and c is the vacuum speed of light. For the GPS L1 and L2 bands, $f_1 = 154 f_0$ and $f_2 = 120 f_0$, where f_0 = 10.23 MHz. The pseudorange (or code) estimations, P1 and P2, are communicated in meters, while phase estimations, L1 and L2, are communicated in cycles. In the accompanying, we utilize "clock" to mean a period balance between a collector or satellite clock and GPS System Time as decided from either code or phase estimations on distinctive frequencies or some blend of them.

The code and phase measurements are modelled as:

$$\begin{aligned}
P_1 &= D_1 + \Delta h_p + (e + \Delta\tau_p) \\
P_2 &= D_2 + \Delta h_p + \gamma(e + \Delta\tau_p) \\
\lambda_1 L_1 &= D_1 + \lambda_1 W + \Delta h - (e + \Delta\tau) - \lambda_1 N_1 \\
\lambda_2 L_2 &= D_2 + \lambda_2 W + \Delta h - \gamma(e + \Delta\tau) - \lambda_2 N_2 \qquad (2)
\end{aligned}$$

Where:

- D_1 and D_2 are the geometrical engendering separations between the emitter and collector receiving wire phase focuses at f_1 and f_2 including troposphere extension, relativistic impacts etc.
- W is the contribution of the wind-up effect (in cycles).
- 'e' is the code ionosphere elongation in meters at f_1. This elongation varies with the inverse of the square of the carrier frequency and is applied with the opposite sign for phase.
- $\Delta h = h_i - h^j$ is the difference between receiver i and emitter j ionosphere-free phase clocks. Δh_p is the corresponding term for code clocks.
- $\Delta\tau = \tau_i - \tau^j$ is the difference between receiver i and emitter j offsets between the phase clocks at f_1 and the ionosphere-free phase clocks. By construction, the corresponding quantity at f_2 is $\gamma\Delta\tau$. Similarly, the corresponding quantity for the code is $\Delta\tau_p$ (time group delay).
- N_1 and N_2 are the two carrier-phase ambiguities. By definition, these ambiguities are integers. Unambiguous phase measurements are therefore $L_1 + N_1$ and $L_2 + N_2$.

Equations (2) take into account all the biases related to delays and clock offsets. The four independent parameters, Δh, $\Delta\tau$, Δh_p and $\Delta\tau_p$, are equivalent to the definition of one clock per observable. However, our choice of parameters emphasizes the specific nature of the problem by identifying reference clocks for code and phase (Δh_p and Δh) and the corresponding hardware offsets ($\Delta\tau_p$ and $\Delta\tau$). These offsets are assumed to vary slowly with time, with limited amplitudes.

The measured wide lane ambiguity, $\tilde{N}_w$ (also called the Melbourne-Wubbena wide lane) can be written as:

$$\langle \tilde{N}_w \rangle = N_w + \mu_i - \mu^j \qquad (3)$$

Where N_w is the integer widelane ambiguity, μ^j is the constant widelane delay for satellite j and μ_i is the widelane delay for receiver i (which is fairly stable for good quality geodetic receivers). The symbol < >means that all quantities have been averaged over a satellite pass.

Integer widelane ambiguities are then easily identified from averaged measured widelanes corrected for satellite widelane delays. Once integer widelane ambiguities are known, the ionosphere-free phase combination can be expressed as

$$Q_c = D_c + \lambda_c W + h_i - h^j - \lambda_c N_1 \quad (4)$$

Where $Q_c = (\gamma\lambda_1 L_1 - \lambda_2(L_2 + N_w))/(\gamma - 1)$ is the ionosphere-free phase combination is computed using the known N_w , ambiguity, D_c is the propagation distance, h_i is the receiver clock and h^j is the satellite clock. N_1 is the remaining ambiguity associated to the ionosphere-free wavelength λ_c (10.7 centimeters).

The complete problem is thus transformed into a single-frequency problem with wavelength λ_c and without any ionosphere contribution. Many algorithms can be used to solve Equation (4) using data from a network of stations. If D_c is known with sufficient accuracy (typically a few centimeters, which can be achieved using a good floating-point or real-valued ambiguity solution), it is possible to simultaneously solve for N_1 , h_i and h^j. The properties of such a solution have been studied in detail. A very interesting property of the h^j satellite clocks is, in particular, the capability to directly fix (to the correct integer value) the N_1 values of a receiver that was not part of the initial network.

The majority of the precise-point-positioning ambiguity-resolution (PPP-AR) [5-7] implementations are based on the identification and use of the two quantities $\mu^j$and h^j. These quantities may be called widelane biases and integer phase clocks, a decoupled clock model or uncalibrated phase delays, but they are all of the same nature.

3. A REAL-TIME PPP-AR IMPLEMENTATION

A PPP-AR method [8,9] was effectively actualized by the space centers continuously in the supposed PPP. In this demonstrator and in the system of the International GNSS Service (IGS) Real-Time Service (RTS) [5, 6] and the RTCM, the GPS constellation orbits and clocks are computed. Additional biases for GPS ambiguity resolution are computed and broadcast to the user. The demonstrator also provides an open-source implementation of the method on the user side, for test purposes. Centimeter-level positioning accuracy in real time is obtained on a routine basis.

A. Limitations of the Bias Formulations.

The present detailing works however it has a few disadvantages:

- The picked representation is reliant on the executed technique. Regardless of the fact that the way of the inclinations is the same, their representation may be diverse as indicated by the hidden strategies, and this makes it troublesome for an institutionalization of the inclination messages.
- The user side must execute the same technique as the one utilized on the system side. Something else, the user side would need to change over the amounts starting with one technique then onto the next, prompting potential bugs or misinterpretations.
- It is restricted to the double frequency case. There are just two amounts to be registered in the double recurrence case, however in the triple-recurrence case; there are numerous more conceivable mixes. For instance, one can have (this is a non-comprehensive rundown) where the records allude to diverse sets of frequencies, and other without ionosphere blends, for example, phase widelane-just or even phase without ionosphere and sans geometry mixes are conceivable.

B. New RTCM SSR Model

The new model, as proposed by the RTCM Special Committee 104 SSR working gathering for phase predisposition messages is in light of the thought that the phase-bias is natural to every recurrence. Subsequently, as opposed to making particular blends, one phase-bias for each phase detectable is recognized and telecast. It is noticed that this tradition was received quite a while back for code predispositions. To be sure, in the RTCM structure, and dissimilar to the standard differential code predisposition (DCB) tradition where code predispositions are undifferenced yet consolidated, the RTCM SSR code inclinations are characterized as undifferenced and uncombined. The general model for uncombined code and phase predispositions is subsequent.

$$\begin{aligned}
P_1' &= P_1 + \Delta b_{p1} = D + e + \Delta h_p \\
P_2' &= P_2 + \Delta b_{p2} = D + \gamma e + \Delta h_p \\
\lambda_1 L_1' &= \lambda_1(L_1 + \Delta b_{L1}) = D - e + \Delta h_p - \lambda_1 N_1 \\
\lambda_2 L_2' &= \lambda_2(L_2 + \Delta b_{L2}) = D - \gamma e + \Delta h_p - \lambda_2 N_2 \qquad (5)
\end{aligned}$$

Time group delays τ, and phase clocks h, in Equation (2) are replaced by code and phase biases ($\Delta b_p$and Δb_L respectively). RTCM SSR code and phase biases correspond to the satellite part of these biases. The prime notation denotes the "unbiasing" process of the measurements. Here, the clock definition is crucial. As the biases are uncombined, they are referenced to the clocks. The convention chosen for the standard is natural: it is the same as the one used by IGS, that is Δh_p in our notation.

This new model can be extended to the triple-frequency case very easily, as it does not involve explicit dual-frequency combinations:

$$P_1' = P_1 + \Delta b_{p1} = D + e + \Delta h_p$$
$$P_2' = P_2 + \Delta b_{p2} = D + \gamma_2 e + \Delta h_p$$
$$C_5' = C_5 + \Delta b_{C5} = D + \gamma_5 e + \Delta h_p$$
$$\lambda_1 L_1' = \lambda_1 (L_1 + \Delta b_{L1}) = D - e + \Delta h_p - \lambda_1 N_1$$
$$\lambda_2 L_2' = \lambda_2 (L_2 + \Delta b_{L2}) = D - \gamma_2 e + \Delta h_p - \lambda_2 N_2$$
$$\lambda_5 L_5' = \lambda_5 (L_5 + \Delta b_{L5}) = D - \gamma_5 e + \Delta h_p - \lambda_5 N_5 \qquad (6)$$

This new model simplifies the concept of phase biases for ambiguity resolution. This representation is very attractive because no assumption is made on the method used to identify phase biases on the network side. All the implementations are valid if they respect this proposed model. It also allows convenient interoperability if the network and user sides implement different ambiguity resolution methods. Table 1 summarizes the different messages used for PPP-AR in the context of RTCM SSR:

Parameter Nature	RTCM message	Quantity
GPS orbits/clocks	1060/1066	D, h_p
GPS code biases	1059/1065	b_p
GPS phase biases	1265	b_L

Table 1. RTCM SSR messages for PPP-AR.

C. Bias Estimation in the Dual-Frequency Case.

The new phase biases recognizable proof in the double recurrence case is clear. There are two inclinations to be assessed utilizing two blends (μ and h). The issue to be tackled is depicted in figure 1.

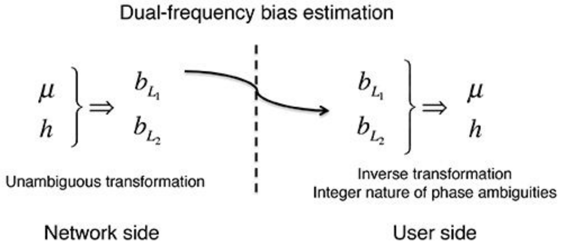

Figure 1. Phase biases estimation in the dual-frequency case.

It can be solved very easily on the network side by means of a 2 × 2 matrix inversion:

$$\begin{pmatrix} b_{L1} \\ b_{L2} \end{pmatrix} = \frac{1}{\gamma_2 \lambda_1 - \lambda_2} \begin{pmatrix} -\lambda_2 & 1 \\ \gamma_2 \lambda_1 & 1 \end{pmatrix} \begin{pmatrix} \mu - \alpha_{21} b_{P1} - \alpha_{22} b_{P2} \\ (\gamma_2 - 1)(h - h_p) \end{pmatrix} \qquad (7)$$

Where

$$\alpha_{21} = \frac{\lambda_1 - \lambda_2}{\lambda_1 + \lambda_2} / \lambda_1$$
$$\alpha_{22} = \frac{\lambda_1 - \lambda_2}{\lambda_1 + \lambda_2} / \lambda_2$$

Note: All the quantities denote the satellite part of the Δ operator defined above.

D. Bias Estimation in the Triple-Frequency Case.

The triple-recurrence inclination distinguishing proof is dubious because of the need, utilizing just three predispositions, to keep the whole number nature of phase ambiguities on all suitable without ionosphere mixes, and specifically blends that were not utilized as a part of the ID process. At this level, one can't make suppositions on what sort of blends will be utilized by a user. The issue to be tackled is portrayed in figure 2.

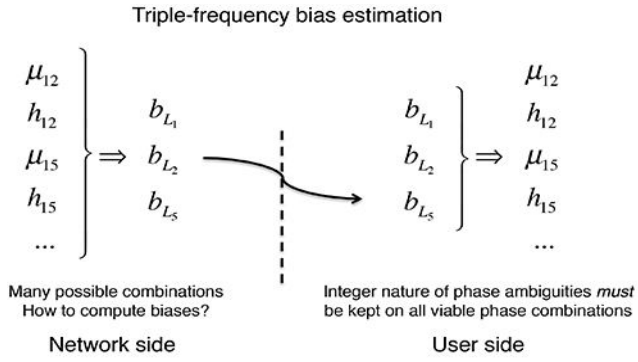

Figure 2. Phase biases estimation in the triple-frequency case.

As a case, a gullible arrangement would be to recognize the additional wide path phase-bias utilizing the double recurrence wide path methodology, and after that distinguish the inclination. Given the expansive wavelength of the additional widelane mix, such distinguishing proof would be simple. Be that as it may, the comparing inclination would be useful for additional widelane ambiguity ID, and its clamor would keep its utilization for widelane 15 (L1/L5) equivocalness determination or other helpful mixes accessible in the triple-recurrence setting.

Every autonomous phase-bias can be specifically evaluated in a channel; notwithstanding, to continue rising similarity with the double recurrence case amid the arrangement period of the new modernized satellites, we have decided to stay in the old structure, that is, to work with blends of predispositions. The determination strategy is the accompanying.

The wide path predispositions, that is, the distinguishing proof of all the $b_{Li} - b_{Lj}$ quantities, are solved. For this computation and in order to have an accurate estimate of these biases, the two MW-widelane biases μ_{12} and μ_{15} are used coupled to an extra phase-bias, which is given by the triple-recurrence without ionosphere phase mix with the whole number widelane ambiguities effectively altered. This last mix utilizing just phase estimations is a great deal more exact than

MW-widelanes. The framework to be comprehended is repetitive and the clamor of the distinctive mathematical statements must be picked precisely. The staying inclination (b_{Li}) is estimated using the traditional ionosphere-free phase combination of L1 and L2.

4. SIMULATION RESULTS AND ANALYSIS

To demonstrate the legitimacy of the idea, we process a few ambiguity blends utilizing genuine information. The procedure is the accompanying:

- Look for good beneficiary areas having countless Block IIF satellites (transmitting the L5 signal) in perspective for a time of time surpassing 30 minutes, and pick among them, one taking an interest in the IGS Multi-GNSS test. In that period, four Block IIF satellites were obvious at the same time (PRNs 1, 6, 9, 30) for an aggregate of 14 GPS satellites in perspective
- For distinctive equivocalness gauges, figure and plot the acquired residuals.

We exhibit in the accompanying diagrams different ambiguity residuals for the four Block IIF satellites in perspective. The estimations of every ambiguity are counterbalance by a whole number worth for clarity purposes.

i. Melbourne-Wubbena Extra-Widelane.

Figure 3 speaks to the MW extra-widelane (between frequencies L2 and L5) ambiguity estimation utilizing our procedure. The MW additional widelane vagueness has a wavelength of 5.86 meters. The clamor of the mix communicated in cycles is low, and the whole number nature of ambiguities in this mix is clearly visible.

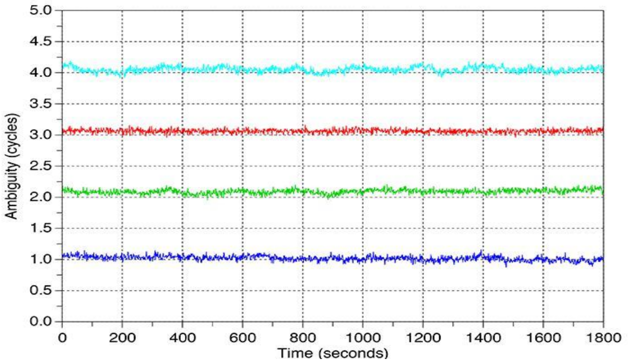

Figure 3. Ambiguity residuals for the extra-widelane 5-2 combination.

Figure 4 speaks the North-East-Up (NEU) position error and figure 5 shows the horizontal positioning error.

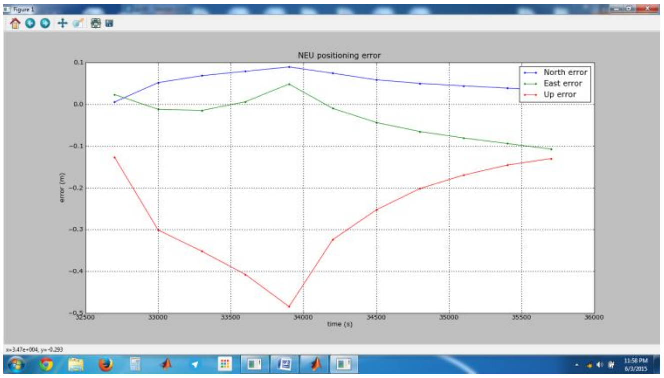

Figure 4: NEU Position Error

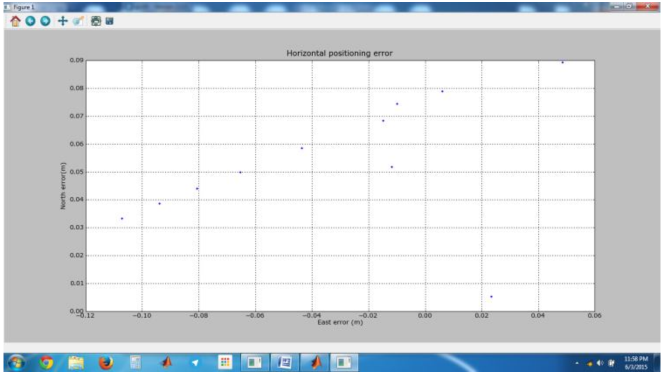

Figure 5: Horizontal position error

The earth's atmosphere modifies the speed and direction of propagation of the GNSS signals. This effect, referred to as refraction, generates a propagation delay, i.e. the signal transit time is changed. Two layers of the atmosphere affect particularly the propagation of the GNSS signals: the ionosphere and the troposphere. Figure 6 shows the zenith troposphere delay and figure 7 represents the ionosphere combination.

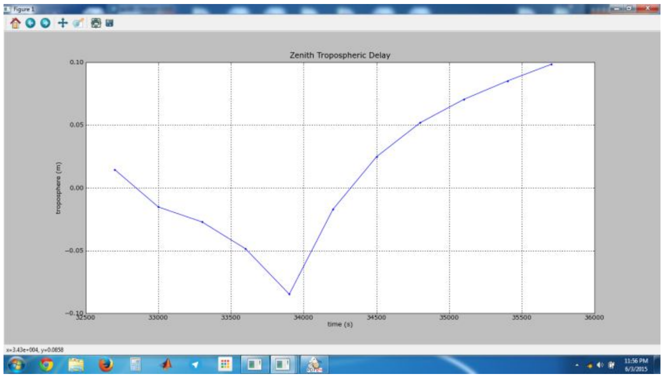

Figure 6: Zenith Troposphere Delay

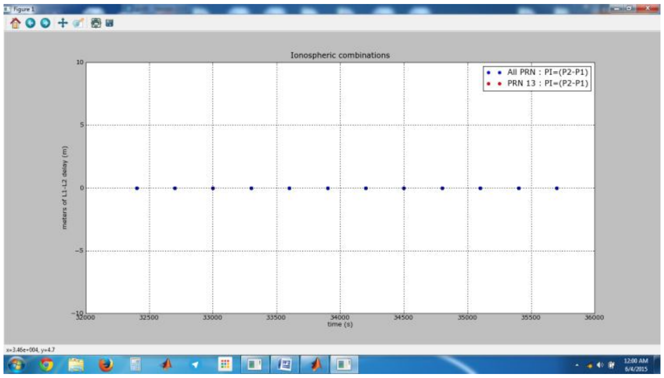

Figure 7: Ionosphere combinations

Figure 8 represents as carrier phase ambiguities, the various dilution of precision such as VDOP, HDOP, GDOP, and TDOP shows in figure 9.

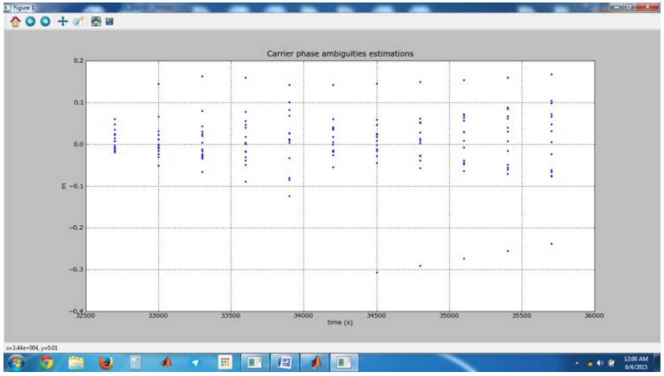

Figure 8: carrier phase ambiguities

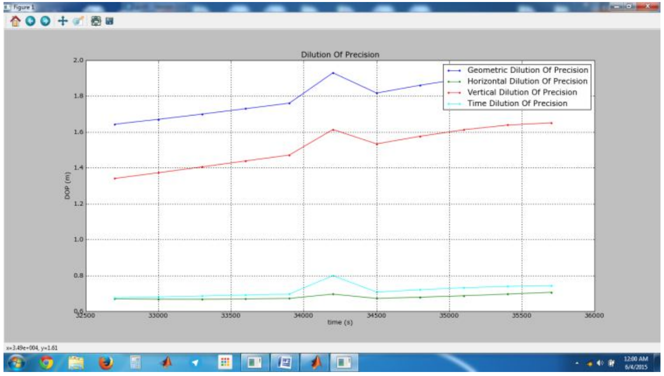

Figure 9: Dilution of precision

Figure 10 and figure 11 shows the both residuals i.e. prefit and postfit residuals of pseudorange as well as carrier phase.

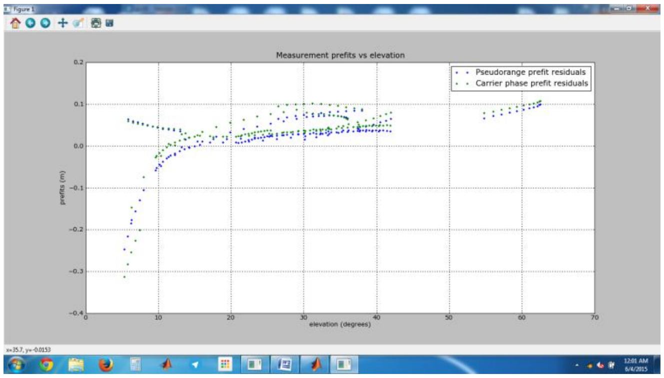

Figure 10: prefit residuals

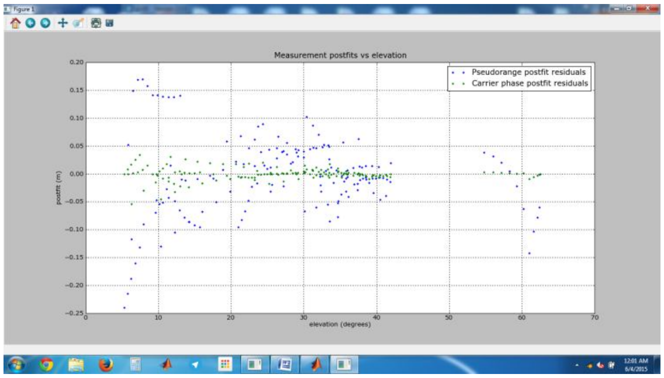

Figure 11: post fit residuals

ii. Application to Triple-Frequency PPP

The outcomes exhibited above demonstrate that the whole number vagueness nature of phase estimations is preserved for different valuable detectable blends and demonstrate the legitimacy of the model. Another test has been done to gauge the effect of equivocalness merging in the triple-recurrence connection. For that, with a specific end goal to amplify the discernibleness of the GPS Block IIF group of stars and hence the precision of the predispositions, a system of ten stations crosswise over Europe has been decided for the phase-bias processing. The four Block IIF satellites were noticeable at the same time (PRNs 1, 3, 6, 9) for an aggregate of 10 satellites in perspective.

The PPP-Wizard open source customer was utilized to perform PPP continuously. The benefit of this execution is that it straightforwardly takes after the uncombined perceptible definition depicted in Equations (5). The methodology for vagueness determination is a basic bootstrap approach.

iii. Convergence of the Widelane-Only Solution.

In this test, a PPP arrangement was performed, however just the altering of the widelane ambiguities was actualized. As noted in the past segment, the wavelength of the widelane ambiguity when the additional widelane equivocalness is tackled is around 3.4 meters, so it is normal that all the widelanes can be altered in a brief while. Regardless of the intensification variable of around 20 of the comparable unambiguous phase mix, we hope to get an exactness of around 10 centimeters with such an answer.

The additional widelanes are altered momentarily; the remaining widelanes are settled in around two minutes overall to be underneath 30 centimeters (this is spoken to by the distinctive sharp decreases of the slips). This new setup, accessible in the triple-frequency setting, is exceptionally fascinating as it gives a middle of the road class of precision, which unites rapidly and which is suitable for applications that don't request centimeter exactness. Another intriguing part of this blend is the whole crossing over component. In PPP, whole connecting is the usefulness that permits us to recoup the whole number nature of the ambiguities after a loss of the collector estimations more than a brief time of time (ordinarily a go through a passage or under a scaffold). This is done more often than not by method for the estimation of a without geometry blend (ionosphere delay estimation) amid the hole.

Sensible greatest whole span in the double recurrence case is around one moment. In the triple-recurrence case, the wavelength of the sans geometry mix including the widelane (if the additional widelane is settled) is 1.98 meters. With such an extensive wavelength, the holes are much simpler to fill, and we can securely extend the crevice term to a few minutes. Furthermore, the widelane blends are twist up autonomous, so there is no compelling reason to screen a conceivable turn of the reception apparatus amid the crevice, as in the double recurrence case.

iv. Overall Convergence (All Ambiguities).

Another PPP [10, 11] union test has been done with all ambiguities altering actuated (four unique keeps running of 15 minutes are superimposed).The centimeter precision is gotten in this arrangement inside of eight minutes, which is a critical change in correlation to the double recurrence case. Further change of this joining time is normal with an increment in the quantity of Block IIF satellites and, accordingly, GPS IIIA satellites.

v. Convergence Time Comparison between the Dual- and Triple-Frequency Contexts.

Because of these new results, a practical picture for PPP joining in the double and triple-recurrence connections can be drawn. To do as such, polynomial capacities have been fitted over the information focuses acquired in the past studies. Two information sets were utilized:

- Standard double recurrence meeting (GPS just, 10 satellites in perspective).
- Triple-recurrence union (GPS just, 10 satellites in view, four Block IIF satellites). Figure 12 demonstrates the practical PPP merging correlation between double and triple-recurrence connections (level position slip).

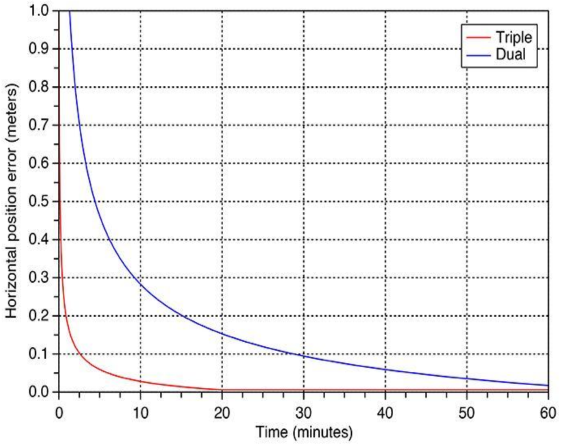

Figure 12: Represents the comparison between the two polynomials (horizontal error).

5. CONCLUSION

The new phase-bias idea proposed for RTCM SSR has been effectively executed in the IGS ongoing investigation focus. This new idea speaks to the phase-bias in an uncombined structure, not at all like the past details. It has the upside of the unification of the distinctive proposed routines for ambiguity determination, and it sets us up for the future; for instance, for a generally accessible triple-recurrence situation. The legitimacy of this idea has been demonstrated; that is, the whole number equivocalness nature of phase estimations is monitored for different valuable recognizable blends. Furthermore, we have likewise demonstrated that the triple-recurrence setting has a critical effect on vagueness meeting time. The general union time is radically lessened (to a few minutes rather than a few several minutes) and there is a middle of the road mix (widelane-just) that makes them intrigue properties as far as joining time, precision and hole crossing over for non-requesting centimeter-level applications.

6. REFFERENCES

1. D. Laurichesse **"Phase Biases Estimation for Undifferenced Ambiguity Resolution"** by *PPP-RTK & Open Standards Symposium, Frankfurt, Germany, March 12–13, 2012.*
2. P. Collins, S. Bisnath, F. Lahaye, and P. Héroux **"Undifferenced GPS Ambiguity Resolution Using the Decoupled Clock Model and Ambiguity Datum Fixing"** *in Navigation, Journal of The Institute of*

Navigation, Vol. 57, No. 2, Summer 2010, pp. 123–135, doi: 10.1002/j.2161-4296.2010.tb01772.x.

3. D. Laurichesse, F. Mercier, J.-P. Berthias, P. Broca, and L. Cerri **"Integer Ambiguity Resolution on Undifferenced GPS Phase Measurements and Its Application to PPP and Satellite Precise Orbit Determination"** *in Navigation, Journal of The Institute of Navigation, Vol. 56, No. 2, Summer 2009, pp. 135–149, doi: 0.1002/j.2161-4296.2009.tb01750.x.*
4. M. Ge, G. Gendt, M. Rothacher, C. Shi, and J. Liu **"Resolution of GPS Carrier-Phase Ambiguities in Precise Point Positioning (PPP) with Daily Observations"** *in Journal of Geodesy, Vol. 82, No. 7, pp. 389–399, doi: 10.1007/s00190-007-0187-4. Erratum: 10.1007/s00190-007-0208-3.*
5. G. Wübbena, M. Schmitz, and A. Bagge, **"PPP with Ambiguity Resolution (AR) Using RTCM-SSR"** *IGS Workshop, Pasadena, Calif., June 23–27, 2014.*
6. A. Boriskin, D. Kozlov, and G. Zyryanov **"The RTCM Multiple Signal Messages: A New Step in GNSS Data Standardization"** *in Proceedings of ION GNSS 2012, the 25th International Technical Meeting of The Satellite Division of the Institute of Navigation, Nashville, Tenn., September 17–21, 2012, pp. 2947-2955.*
7. G. Wübbena "**RTCM State Space Representation (SSR): Overall Concepts Towards PPP-RTK"** *presented at PPP-RTK & Open Standards Symposium, Frankfurt, Germany, March 12–13, 2012.*
8. M. Caissy, L. Agrotis, G. Weber, M. Hernandez-Pajares, and U. Hugentobler **"Coming Soon: The International GNSS Real-Time Service"** *in GPS World, Vol. 23, No. 6, June 2012, pp. 52–58.*
9. D. Laurichesse **"The Real-time PPP with Undifferenced Integer Ambiguity Resolution Demonstrator"** in *Proceedings of ION GNSS 2011, the 24th International Technical Meeting of The Satellite Division of the Institute of Navigation, Portland, Ore, September 20–23, 2011, pp. 654–662.*
10. S. Banville, **"Improved Convergence for GNSS Precise Point Positioning"** *Ph.D. dissertation, Department of Geodesy and Geomatics Engineering, Technical Report No. 294, University of New Brunswick, Fredericton, New Brunswick, Canada. Recipient of the Institute of Navigation 2014 Bradford W. Parkinson Award.*
11. S.B. Bisnath and Y. Gao "**Precise Point Positioning: A Powerful Technique with a Promising Future"** in GPS World, Vol. 20, No. 4, April 2009, pp. 43–50.