Real-time PPP with undifferenced integer ambiguity resolution, experimental results

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BIOGRAPHY

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ABSTRACT

It was shown in 2007 [1] that using pseudo-range information it becomes possible to fix the ambiguities on zero-difference GPS phase measurements for a global network. Theoretically, such a solution has the same performance and observability as a pseudo-range solution, but with measurements errors below 1cm. Thus an important activity has grown on this subject in recent years.

The dual frequency pseudo-range information were used to fix the difference of the two ambiguities (one ambiguity for each frequency) using the Widelane (Melbourne-Wubbena) four observables combination [1, 4].

The remaining ambiguity is solved in a zero-difference network solution on the ionosphere free phase combination. The corresponding clocks corrections (GPS satellites and receivers) correspond to 'phase clocks'. These clocks have the property of preserving the integer nature of the ambiguities when processing the phase measurements of an isolated receiver. This allows the precise positioning (PPP) with integer ambiguity fixing. Since November 2009, such constellation clock solutions are available in the CNES/CLS IGS analysis centre solution ('grg' solution).

Other approaches were developed in [8], where biases are identified relatively to a reference orbits/clocks solution (for example an igs solution), to allow the preservation of the satellite/satellite single difference ambiguities at user level. Also in [6], Collins presented a unified formulation for these kinds of problems (the 'decoupled clock model').

The application to real time solutions is very promising, because the ambiguity fixing improves drastically the performance of the solutions. This was shown in [1, 3]. The core of the real-time implementation is a Kalman filter working in mixed-mode (with both real- and integer-valued phase ambiguities). The filter produces GPS constellation states (orbits and clocks) with the 'integer' property. Algorithms for user receivers are also introduced.

In order to improve the user ambiguity fixing, the code/phase biases have been added to the current solution. This allows also being compliant with the parameterization used in the IGS real time pilot project in which CNES is participating since July 2010.

The recent improvements achieved at CNES in the real time solution are shown, including user side results. We present several 'site survey'-type real-time experiments, which demonstrate an achieved horizontal precision close to 1 cm RMS. This is about one order of magnitude better than standard PPP solutions, which rely upon floating ambiguity fixing, and very close to the precision of differential RTK.

In this article some properties of the related hardware characteristics are also shown (evolution of the widelane biases and possible variations of the code/phase biases).

Future work and long-term objectives of the demonstrator are outlined.

1. INTRODUCTION

Integer ambiguity resolution is routinely applied on double differenced GPS phase measurements to achieve precise positioning. Double-differencing is very powerful because it removes most of the common errors between the different signal paths, including biases, making it easier to identify integer ambiguities. Double-differencing also minimizes the size of the problem to be solved by removing all the clock contributions. This technique is the basis for very precise differential positioning.

Precise Point Positioning (PPP) is an alternative approach to perform precise positioning. In this technique, zero-difference measurements are used in combination with precise orbits and clocks for the GPS constellation. The performance of the method is directly related to the quality of these input orbits and clocks, which are computed using data collected over a world-wide network of stations. PPP is a very powerful tool, in particular to track moving receivers, however, until recently it lacked the ability to fix integer ambiguities.

We have recently shown [1, 5] that it is possible to directly fix integer ambiguities on zero-difference phase measurements. The process is a two steps procedure, where the difference of the two ambiguities (one for each frequency) is first fixed using the four observables widelane combination (Melbourne Wubbena). No geometrical model is needed for this first step (orbits, clocks, receiver positions …). Then the remaining ambiguity is fixed in a global network solution, using the models and the ionosphere free phase combination.

Phase measurements then become unambiguous pseudorange-like measurements with a few millimeter noise level. In the process, the clocks corrections related to the ionosphere free phase combination are estimated. These phase clocks preserve the integer nature of the ambiguities when processing the phase measurements of an isolated receiver. This allows the precise positioning (PPP) with integer ambiguity fixing. Since November 2009, such constellation clock solutions are available in the CNES/CLS IGS analysis centre solution ('grg' solution).

The general formulation is first summarized (widelane ambiguity fixing, remaining ionosphere free narrowlane ambiguity fixing). The corresponding satellite widelane biases are defined, and are shown to be very stable over long durations. The ionosphere-free code/phase biases are also defined, and can be estimated in the global solution. These code/phase biases are needed to achieve a better model of the ionosphere-free pseudo-range observables. The long term stability of these biases is also shown.

Similar biases were defined by other authors [8], but for a very different purpose. The objective in these studies is to reconstruct phase clocks (in order to obtain integer ambiguities in PPP solution) from a standard code/phase global solution, like one of the IGS solutions. Depending on the stability of the reference clock solution, these biases may have different behaviors. In the present formulation, the phase clocks are directly referenced to the phase observables, and are defined without any code/phase biases.

1.1. NOTATIONS AND MODEL EQUATIONS

In this paper, we use the following notations:

$$\gamma = \frac{f_1^2}{f_2^2}, \quad \lambda_1 = \frac{c}{f_1}, \quad \lambda_2 = \frac{c}{f_2}$$

where f_1 and f_2 are the two frequencies of the GPS system and c is the speed of light. For GPS L_1 and L_2 bands, $f_1 = 154 f_0$ and $f_2 = 120 f_0$, where $f_0 = 10.23\,\text{MHz}$. Pseudorange or code measurements, P_1 and P_2, are expressed in meters, while phase measurements, L_1 and L_2, are expressed in cycles.

The pseudorange and phase measurements are modeled as:

$$\begin{array}{rlllll} P_1 = & D_1 & +\Delta h_p & +(e+\Delta\tau_p) & & \\ P_2 = & D_2 & +\Delta h_p & +\gamma(e+\Delta\tau_p) & & \\ \lambda_1 L_1 = & D_1+\lambda_1 W & +\Delta h & -(e+\Delta\tau) & -\lambda_1 N_1 & \\ \lambda_2 L_2 = & D_2+\lambda_2 W & +\Delta h & -\gamma(e+\Delta\tau) & -\lambda_2 N_2 & \end{array} \qquad (1)$$

Where:

- D_1 and D_2 are the geometrical propagation distances between the emitter and receiver phase centers at f_1 and f_2 including troposphere elongation, relativistic effects, etc.

- W is the contribution of the wind-up effect (in cycles).

- e is the ionosphere elongation in meters at f_1. This elongation varies with the inverse of the square of the frequency and with opposite signs between phase and code.

- $\Delta h = h_i - h^j$ is the difference between receiver *i* and emitter *j* ionosphere-free phase clocks. Δh_p is the corresponding term for pseudorange 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 pseudorange 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 phases measurements are therefore $L_1 + N_1$ and $L_2 + N_2$.

These equations take into account all the biases related to delays and clocks. The four independent parameters $\Delta h, \Delta \tau, \Delta h_p, \Delta \tau_p$ 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 pseudorange 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.

1.2. GENERAL OVERVIEW OF THE METHOD

The key characteristics of the method are summarized hereafter.

According to [1, 5], the measured widelane $\tilde{N}_w$ (also called the Melbourne-Wübbena widelane) can be written as:

$$\langle \tilde{N}_w \rangle = N_w + \mu_i - \mu^j \qquad (2)$$

where N_w is the integer widelane ambiguity, μ^j is the constant widelane delay for satellite j, μ_i is the widelane delay for receiver i (fairly stable for good geodetic receivers). The symbol $\langle \ \rangle$ means that all quantities have been averaged over a pass.

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

$$Q_c = D_c + \lambda_c W + h_i - h^j - \lambda_c N_1 \qquad (3)$$

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

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 (3) over a network of stations. If D_c is known with sufficient precision (typically a few centimeters, which can be achieved using a good floating ambiguity solution), it is possible to simultaneously solve for N_1, h_i and h^j.

The properties of a such a solution have been studied in details. A very interesting property of the h^j satellites clocks is, in particular, the capability to directly fix the N_1 values of a receiver which has not been part of the initial network [5].

2. REAL TIME IMPLEMENTATION OF THE METHOD

As shown in figure 1 our PPP approach involves the following steps:

- On the network side, raw data are collected, zero-difference widelanes are fixed for each receiver, then N1 ambiguities are fixed for the network and 'integer' clock by-products are generated and broadcast to users.

- On the user side, zero-difference widelanes are fixed, and then 'integer' clocks are used to fix N1 ambiguities and to estimate the stochastic position of the receiver, leading to "absolute" centimeter level PPP.

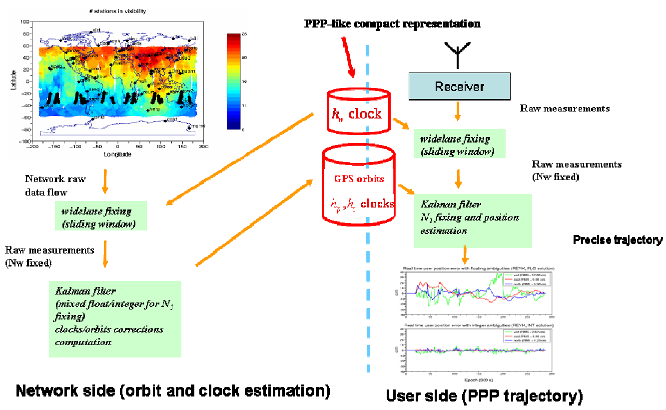

Fig. 1. Integer PPP diagram

We will now show how these operations can be performed in real time.

2.1. REAL TIME WIDELANE AMBIGUITY FIXING

Zero-difference widelane integer ambiguity fixing is based upon computing the Melbourne-Wübbena widelane from raw measurements and subtracting predefined satellites biases. In order to reduce measurement noise, an averaging over some time period is required.

In the real-time process, this is obtained using a sliding averaging window. The drawback of this method is that the integer widelane is only known after a certain period of time (equal to the length of the window). The optimal window length is thus the result of a trade-off between the delay of the estimation and the success rate of the ambiguity fixing.

This success rate is also highly correlated to the quality of the pseudorange measurements, which is itself directly related to the elevation angle. This is the reason why we consider two options, one which includes all available measurements, the other which only deals with measurements with an elevation above 30°.

Indeed, when a user turns on his receiver, it is likely that a few satellites will be seen at high elevation angles, and thus are in a better configuration in term of pseudorange noise. On the other hand, on the network side, and in converged mode, new satellites always appear with low elevation angles. Thus different window lengths should be used in user mode and in network mode.

Figure 2 shows statistics of widelane fixing with various window lengths (between 5 minutes and 1 hour) and for a representative set of 30 stations, compared to a reference post-processed solution.

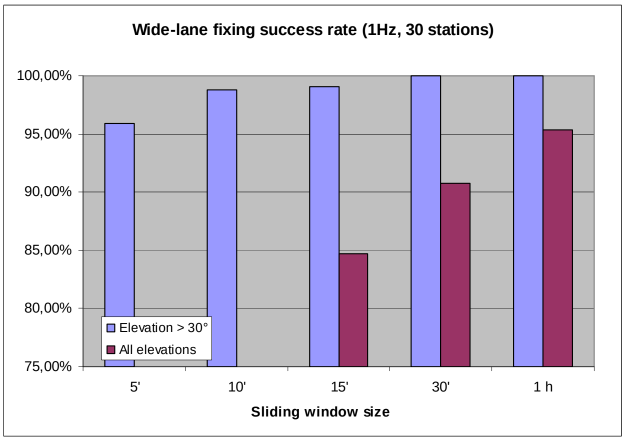

Fig. 2. Wide lane fixing success rate

Our experience shows that 30 minutes and 5 minutes are good window lengths for widelane fixing, for contemporary receivers, for low and high elevation angles respectively.

In the following paragraphs, we will assume that the widelane is fixed during preprocessing, and we will focus on real time N1 fixing and integer clocks generation.

2.2. REAL TIME NARROWLANE AMBIGUITY FIXING

An extended Kalman filter is used to compute the clocks over the network. The parameters estimated in the filter are detailed in the following table:

Table 1: Kalman filter parameters

Parameter nature	Quantity	Typical number
satellite phase clock	1 per satellite	34
station phase clock	1 per station	50
code/phase satellite clock bias	1 per satellite	34
code/phase station clock bias	1 per station	50
zenith troposphere delay	1 per station	50
station coordinates corrections	3 per station	50*3
satellite orbit corrections (R,T,N)	3 per satellite	34*3
Phase ambiguities	12 per station (max)	50*12
		1070

The filter is fed with ionosphere-free pseudorange and phase measurements with measurement noises of 1 m and 1 cm respectively. With a global network of about 50 stations there are about 500 phase measurements and 500 pseudorange measurements at each time step. The time step can vary from 5 seconds to 5 minutes.

The parameter model noises are set to the following values (for a 5 min sampling):

Table 2: Filter model noise

Parameter nature	Value	Comments
Phase satellite clock	∞	Purely stochastic
Phase station clock	∞	Purely stochastic
Code/Phase satellite clock bias	1 mm	
Code/Phase station clock bias	1 cm	
Zenith troposphere delay	1 mm	
Station coordinates (X, Y, Z ITRF)	0	Coordinates are set to 0
satellite orbit corrections(R, T, N)	(0, 4 mm, 2 mm)	Radial correction is set to 0
Phase ambiguities	0	Ambiguities are constant during a pass (initial covariance set to 10 m at the beginning of the pass)

As the primary focus of the test is to evaluate the precision with which satellites clocks can be estimated in real-time using the zero-difference ambiguity fixing technique, stations coordinates are not estimated in the filter; they are set to their ITRF 2005 values.

The real-time N1 integer ambiguity fixing is performed directly by the main Kalman filter. This filter works in the floating domain for all its parameters except for N_1 ambiguities which are set to their integer value once they are known with enough confidence.

At the beginning of a pass, neither N_w nor N_1 are known, so the covariance of the ambiguity is set to an initial value (typically 10 m), and the filter works in floating mode. After 30 minutes, the preprocessing module fixes N_w to its integer value. N_1 can be then fixed in the filter. At this stage, 2 different configurations may arise:

1) The pass is between a satellite and a station that are already linked by other measurements with fixed ambiguities (fig 4). Because of the implicit closure of the equations the covariance on N_1 is already close to the phase measurement noise (typically 1 cm). In this case, N_1 should be already close to an integer, but not yet fixed. It is then fixed to this integer value.

2) The new pass is not constrained by other fixed measurements. N_1 can than be set to any integer.

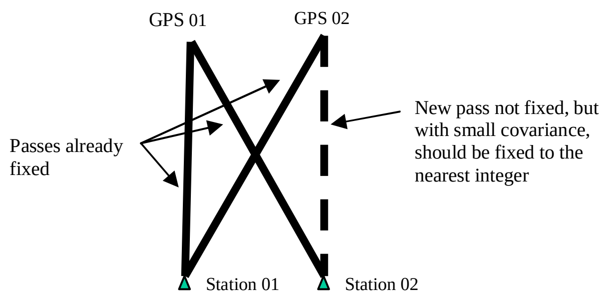

Fig. 3. Connected ambiguities

The choice between the 2 configurations is conducted by a network connectivity test.

The ambiguity fixing process is performed by adding a constraint equation to the filter (new measurement with a noise equal to 0). The fixing of one ambiguity can impact the whole network. It can trigger by continuity the fixing of other ambiguities not fixed yet.

At each time step, we select in our state vector the satellite clocks whose covariances are close to the phase measurement noise. These clocks are said to be 'integer' clocks while the others are 'floating' clocks.

2.3. REAL TIME ORBITS CONSTRUCTION

Despite the recent improvements in IGU orbits quality [13], it is not possible to use these orbits directly, without estimating corrections, the main reason being the degraded quality of orbits during the eclipsing seasons.

The Kalman filter has the possibility of estimating orbits corrections, defined in a local reference frame. It has been shown that this technique can actually improve orbits quality and ambiguity resolution success rate [3]. The drawback of this technique is that the process is complex, time consuming, and may lead to some instabilities, especially when the stations network is not dense enough.

The chosen solution is a trade-off between complexity and robustness. It consists of starting a new instance of the Kalman filter for orbit corrections computation, as soon as a new IGU file is available. This ensures the robustness of the solution, since the orbit solution always starts in the observation phase of the IGU, which is of good quality. To avoid as much as possible the computation burden, a sampling period of 5 minutes was chosen for this filter.

The final real-time orbits construction consist of using the corrected IGUs and to mix them with the older ones using a weighting factor varying linearly from 0 to 1 over a 6 hours interval.

The process used to construct real-time continuous orbits is described in figure 4.

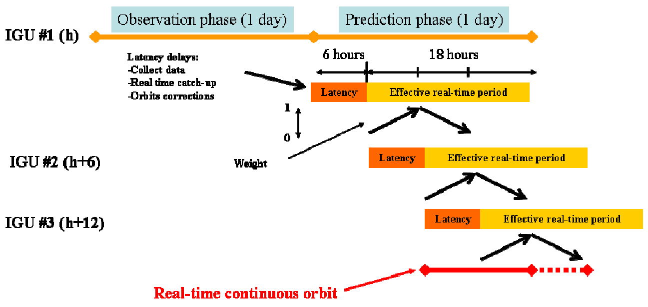

Fig. 4: real-time continuous orbit construction

2.4. HIGH RATE CLOCKS GENERATION

After having computed the real-time orbit, a last Kalman filter is used. In this part of the process, orbits corrections are not estimated. The filter runs at the maximum available rate, the rate of the measurements, which is typically 10 seconds.

2.5. REAL TIME STATE SPACE REPRESENTATION

A standard state space representation consists mainly in orbits and clocks as defined in a sp3 file for example [11]. In [1], we have proposed to add new quantities, adapted to the method. However, in order to benefit from the full potential of the method, we need to refine the nature of these quantities.

Long term evolution of widelane clocks

Figure 5 shows the evolution of the widelane clocks over one year, for the block IIA satellites (upper plot) and for the block IIR satellites (lower plot). The lower plot shows very stable clocks, while the upper plot shows more jumps.

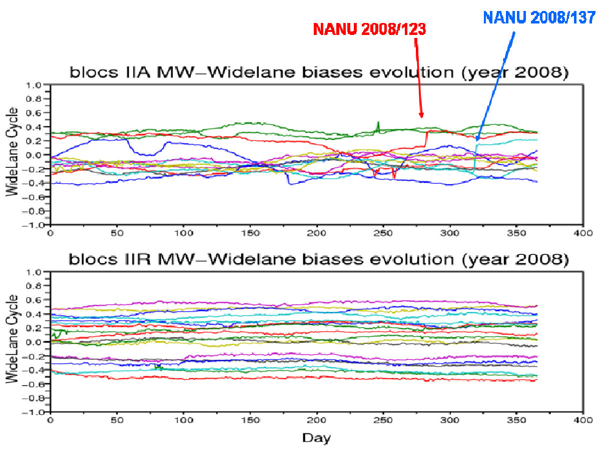

Fig. 5: One year evolution of widelane clocks

Important variations are always correlated to a satellite event (identified in a NANU). Despite these important variations, it is safe to consider that a constant daily value is sufficient to represent these clocks evolutions. It also seems not necessary to introduce a covariance parameter associated with these quantities.

Long term evolution of pseudorange clock and phase clock difference

The difference between pseudorange and phase clocks $h_p^{\,j} - h^j$ has slow and limited variations, as shown by direct comparison of code and phase residuals [6]. This is the reason why we estimate directly this bias in the Kalman filter instead of directly estimate separate pseudorange clocks, along with phase clocks. It allows to finely tune the model noise of this offset according to the actual evolution of this bias.

Figure 6 represents the evolution over one year of the satellite part of these clocks bias (the $h_p^{\,j} - h^j$ term in the equations). The block IIA and block IIR have been separated. The continuity of phase clocks has been maintained (expect for the eclipsing block IIA clocks parts, which have been removed).

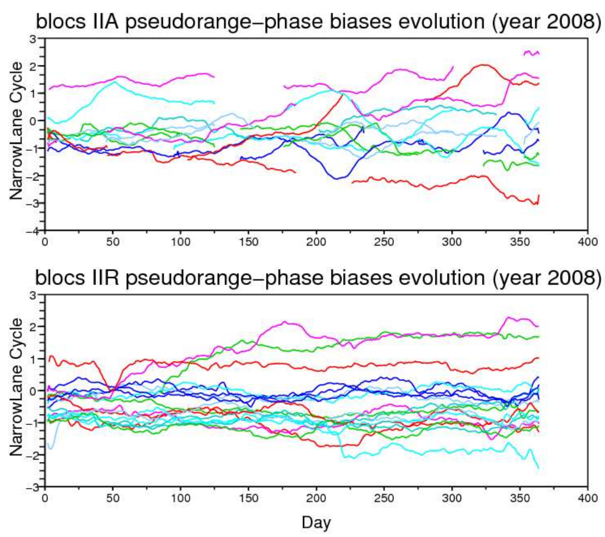

Fig. 6: One year evolution of pseudorange-phase bias

We remark that, although these biases seems to be very stable, and can be considered constant on a daily basis, their long term variations can be far above one narrow lane cycle over one year for both block IIA et block IIR satellites. This is the reason why these biases can not be neglected in the state space representation (phase clocks and pseudorange clocks can not be assimilated to the same quantity on the long term). We can decide to transmit either the estimated phase pseudorange biases, or the reconstructed pseudorange clocks, which can be expressed using the following equation:

$$\underbrace{\overline{h_p^{\ j}}}_{\text{filtered pseudorange clock}} = \underbrace{h^j}_{\text{phase clock}} + \underbrace{\left(h_p^{\ j} - h^j\right)}_{\text{estimated pseudorange-phase baises}}$$

The resulting quantity is equivalent to the pseudorange clock of our model, but smoothed by the model noise of the bias. It is also equivalent to the clock computed with a standard model (a pseudorange clock smoothed by the phase), like the one available in IGS sp3 file for example. This property ensures an ascending compatibility for the new model: phase clocks and widelane clocks are seen as 'complements' over the standard model.

It is also proposed to broadcast the formal covariance of the pseudorange and phase clocks.

Complete representation

The updated real time state space representation is given in Table 3. Modifications to the standard model are highlighted in orange. The importance of a phase clock continuity indicator is addressed in [2].

Table 3. Real time state space representation

Nature	Quantity	Occurrence
GPS Orbits + covariance	3+1 value/satellite (same definition as IGS/sp3 standards)	Each epoch
$\overline{h_p^{\ j}}$ Pseudorange clocks + covariance	1+1 value/satellite (same definition as IGS/sp3 standards)	Each epoch
μ^{emi} (or widelane clock)	1 value/satellite	Daily
h^j Phase clock + covariance	1+1 value/satellite	Each epoch
Last phase clock discontinuity	1 value/satellite	Each epoch

2.6. USER RECEIVER PROCESSING

The user's receiver positioning is performed by an extended Kalman filter. The estimated parameters are:

- The receiver clock.
- The receiver position.
- The zenith troposphere propagation delay.
- A floating/integer ambiguity per pass.

Like in the network clock solution, N1 ambiguities are fixed 'on the fly', once the integer ambiguity for Nw is known. An efficient way to determine if the position is identified with fixed measurements or not is to test its covariance in the filter.

The different phases of the high precision positioning process are presented in figure 7. It is assumed that during the initialization phase, the receiver is not moving (static phase).

The position is initialized using a pseudorange solution. Then measurements are processed with ambiguities estimated as real numbers. When the formal covariance of the position is small enough, ambiguities are evaluated as integer numbers and kinematic positioning is turned on (the position model noise is set to a large value in the filter). No fast initialization algorithm is implemented yet.

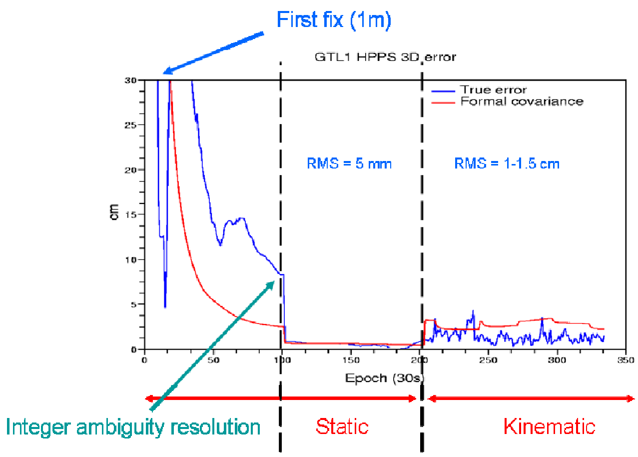

Fig. 7. User initialization and kinematic modes

Typically the initialization phase lasts between 15 and 90 minutes. This rather long initialization time is the main drawback of the method. It is a consequence of the slowly moving geometry of the satellite. It has been confirmed by other authors [7, 9], using other integer estimation methods like the Lambda method [14].

3. EXPERIMENTAL RESULTS

In order to validate the pertinence of the method in actual real-time, CNES has started the development of a full scale demonstrator.

3.1. SYSTEM SIDE ARCHITECTURE

Figure 8 describes the architecture of the system side of the demonstrator. It is in charge of:

1) collecting network measurements
2) computing state-space products
3) disseminating them over the network

A ftp interface is used to retrieve IGS measurements on a daily basis to compute widelane clocks, and on a 6 hour basis to compute real-time orbits. An NTRIP interface, associated with the BNC tool [10], is used to collect network measurements in real time. It is estimated that the latency of these measurements is about 2 or 3 seconds on average. The GNSS engine processes these data and outputs the state space representation described above. The products are then disseminated over the internet, on a web server and a NTRIP caster, either using a modified RTCM message or directly in plain text. The current sampling rate is 10 seconds, while the overall average latency is estimated between 6 to 8 seconds.

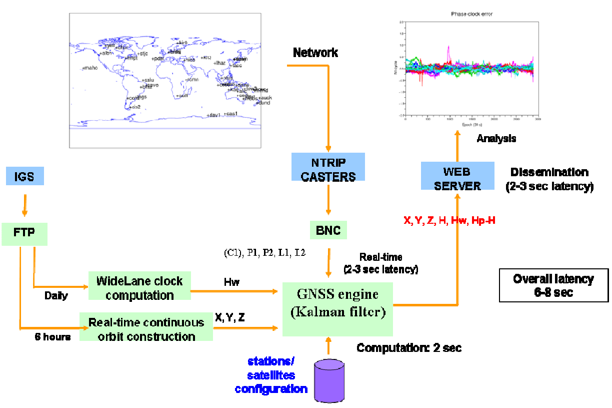

Fig. 8. System side demonstrator architecture

3.2. USER SIDE ARCHITECTURE

The architecture of the user side of the demonstrator is described in figure 9. State space representation is received from a NTRIP caster (or from a web server). The dual frequency observables are read directly from the local receiver.

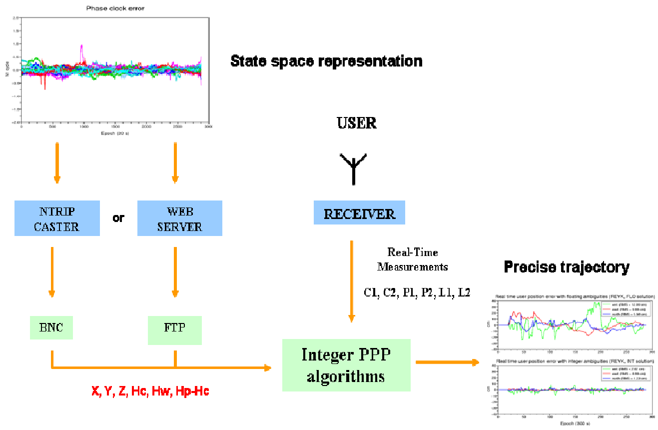

Fig. 9. User side demonstrator architecture

The integer PPP algorithms use the same Kalman filter as the network side. In this case, satellite clocks are not estimated, the receiver position is estimated instead.

3.3. EXPERIMENTAL RESULTS FOR REAL TIME STATE SPACE GENERATION

Network

The goal of the first experiment was to evaluate the quality of the orbits and clocks. Data were downloaded from GFZ and the NrCan NTRIP Casters [10, 16], during one day (14 July 2010), for the network of 50 stations displayed on figure 10.

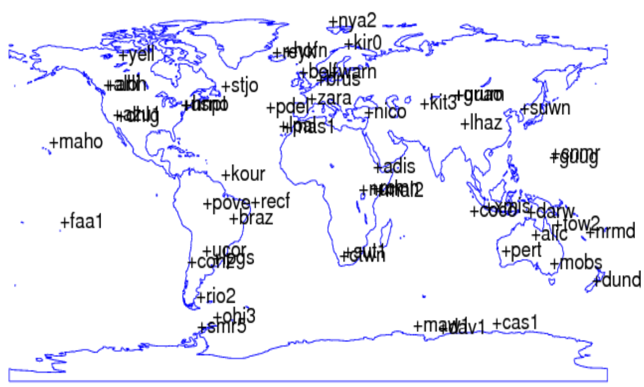

Fig. 10. NTRIP Network

Orbits

Figure 11 shows the difference (expressed in the local orbital frame) between the resulting orbits and IGS final orbits [15] over one day. The average error is about 4 cm RMS 3D, equivalent to what was obtained previously in replay mode [3].

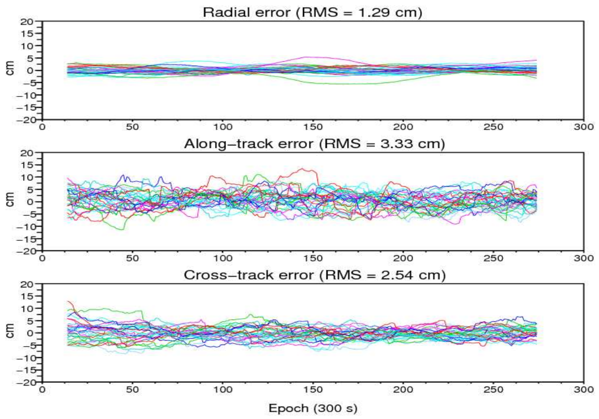

Fig. 11: real-time continuous orbit quality (1 day)

Pseudorange clocks

Pseudorange clocks are compared to the IGS final clocks [15]. In order to account for the absolute nature of these clocks, one common bias is removed per epoch. Results are also corrected for radial orbit differences. The typical RMS error is 5 cm, which is close to the state of the art for this kind of products [12]. No gain was expected from our method because pseudorange measurements are involved in the computation (by opposition to a pure phase clock computation). The 'integer' property of these clocks is also lost in the computation.

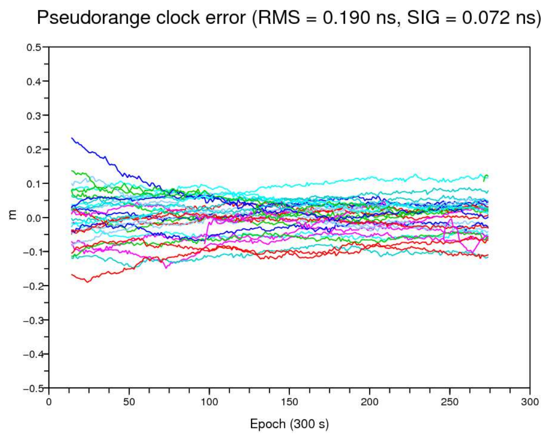

Fig. 12. Real time/reference pseudorange clocks comparison (1 day)

Phase clocks

The comparison of phase clocks with IGS clocks is somewhat more complex. As phase clocks are intended to be used as the same time as ambiguity estimation is performed, it is legitimate to remove both a common bias per epoch and a bias per contiguous satellite clock segment. Results are again corrected for radial orbit errors. The RMS error on phase clocks is below 1 cm. At this level of precision user-side integer ambiguity resolution and associated PPP are easy to obtain.

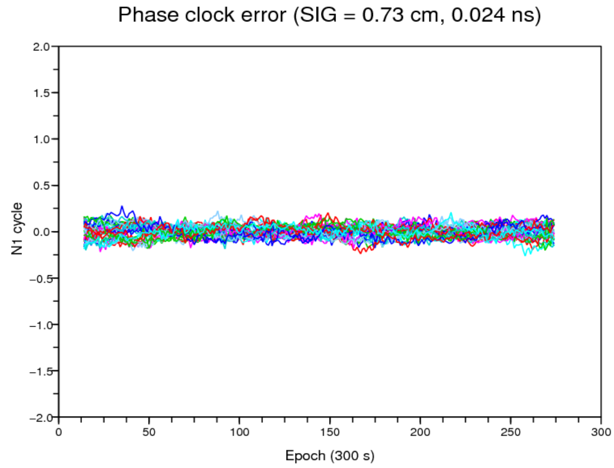

Fig. 13. Real time/reference phase clocks comparison (1 day)

3.4. EXPERIMENTAL RESULTS FOR REAL TIME PPP

Positioning performance in replay mode was presented in [3]. It was shown that sub-centimeter positioning accuracy can be achieved in real-time.

In 2010, an experiment was conducted to evaluate the performance of the demonstrator in actual real time conditions. For this purpose, the demonstrator has been running since December 2009 in a 'limited' mode, that is with a reduced set of stations located in Western Europe (figure 14). The test receiver to be positioned is GTL1, located at CNES facilities in Toulouse, France.

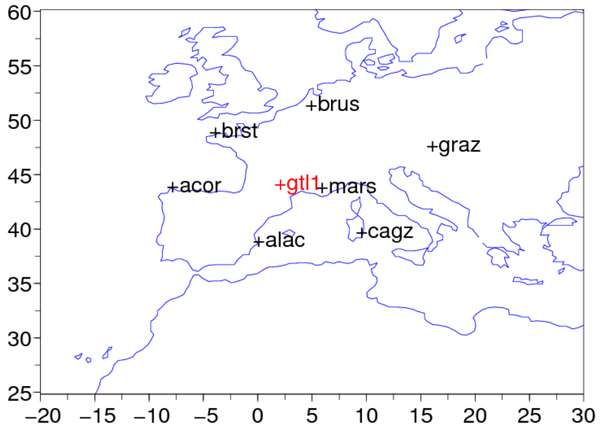

Fig. 14. User-side experimental network

The positioning precision for GTL1 is shown in figure 14. Horizontal position errors are below 1 cm RMS .Instantaneous horizontal errors rarely exceed 2 cm This solution is fully operational. It significantly outperforms standard dual-frequency PPP (by nearly an order of magnitude).

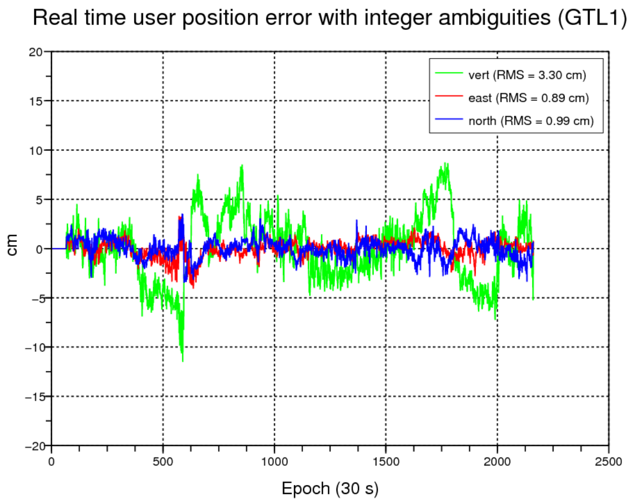

Fig. 15. User-side positioning results

4. AVANTAGES AND DRAWBACKS OF THE METHOD

Table 4 summarizes the advantages and drawbacks of the method. The standard PPP method is a global one with a low precision, the RTK method is a local one with a high precision. CNES 'Integer' PPP method is global, with a high precision. Its main drawback is the convergence time, equivalent to that of PPP, which is not surprising.

Table 4: Methods comparison

	PPP 2-frequencies	RTK 1 or 2 frequencies	CNES Integer PPP 2-frequencies
Geometry	Global	Local < 50 km	Global
Convergence time (TTFF)	Convergence : ~ 30 cm kick start: 1 min static: 15 min dynamic: 30 min	Convergence : ~ 1 cm: 1-5 min	Convergence : ~ 1 cm kick start: 1 min static: 30 min dynamic: 90 min
Horizontal precision	10-50 cm	~ 1 cm	~ 1 cm

5. CONCLUSION AND FUTURE WORK

In [1] a method to fix integer ambiguities on zero-difference GPS measurements over a network of stations was introduced. The GPS integer phase clocks estimated during this process can then be used by any receiver outside of this network for improved accuracy PPP.

This zero-difference integer fixing method has been since extended to real-time, and tested successfully over a global network. We have shown that resulting integer phase clocks have a precision better than 1 cm. We then demonstrated that these clocks can be used by any receiver to perform absolute real time kinematic positioning with about 1 cm accuracy. A full scale demonstrator using this method is under development. It has been running operationally on a limited Western European network since December 2009.

Although initialization of the ambiguity resolution filter in the user receiver can be rather long (close to 1 hour), and still needs to be improved, some potential applications already emerge. These applications include precise site survey, earthquakes monitoring, meteorology, or offshore positioning (buoys, oil rigs).

In 2010, CNES joined the Real Time IGS Pilot Project. The main objective is to process data from the real time IGS network to compute and disseminate 'integer' products on an pre-operational basis to demonstrate the potential of integer clocks for user PPP. This should help support our proposal for the evolution of the RTCM standard in order to allow the dissemination of phase-code biases and clocks. It should be noted that with the current RTCM standard a workaround would need to be found to broadcast the different clock solutions needed by our method.

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