Demonstrating In-The-Field Real-Time Precise Positioning

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BIOGRAPHY

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ABSTRACT

Precise Point Positioning (PPP) is a relatively new positioning technique providing centimeter-level error. PPP processes dual-frequency pseudorange and carrier-phase measurements from a single user receiver, using detailed physical models and corrections, and precise GNSS orbit and clock products calculated beforehand. PPP is different from other precise-positioning approaches like RTK in that no reference stations are needed in the vicinity of the user receiver. The only observation data that must be processed are measurements from the user receiver. Another advantage of PPP is that since the GNSS orbit and clock products are by nature global, the PPP solutions are also global, i.e., the PPP approach works for a receiver located anywhere on or above the Earth surface, and the resulting position is referred to a well-known terrestrial reference frame (normally ITRF). PPP can be applied at post-processing level and also in real-time applications, provided that real-time input orbits and clocks are available. One disadvantage of standard PPP however is its relatively slow convergence time, which is of the order of an hour for decimetric accuracy, as compared to nearly instantaneous convergence with centimetric accuracy in short-baseline RTK.

After the latest launch of GLONASS satellites, the Russian constellation is nowadays fully operational, with 24 operational satellites. The 'GNSS constellation', including GPS and GLONASS, provides currently 54 usable satellites. For the current GNSS user this means that up to 20 GPS+GLONASS satellites can be simultaneously visible in open-sky areas. This represents an increase of around 60% in satellite availability with respect to the GPS-only scenario, and does not count the upcoming Galileo and COMPASS systems.

This high number of satellites in view is very interesting for PPP users, as the convergence time is sensibly

improved when more satellites are used in the PPP solution (decimetric horizontal accuracy can be achieved in less than 20 minutes in many cases). However, the timely provision of accurate GPS and GLONASS orbits and clocks, which requires the proper consideration of inter-system and inter-channel biases, is a challenge for real-time applications.

Over the last two years, GMV has developed an infrastructure for the generation of precise GPS and GLONASS orbits and clocks in real time. This infrastructure acquires via NTRIP data streams from fifty to sixty tracking stations distributed worldwide, and produces orbit updates every fifteen minutes and clock updates every second from a combined GPS and GLONASS solution that can be then used consistently for PPP applications. More recently, a real-time multi-GNSS PPP client has been also developed and integrated in a portable hardware device supporting in-the-field real-time PPP. This device connects to a standard geodetic-class receiver through a serial interface to retrieve the observations, and features mobile communications with the PPP corrections server using mobile Internet or Iridium. The communications have been optimized in order to provide a good balance between the data provider costs (mainly when using Iridium) and the positioning performances. This approach allows the use of a real-time PPP service with many existing geodetic-class receiver without the need for upgrading or replacing them, thus extending their operational capabilities.

In addition to the algorithmic work in the server and client sides, a significant effort has been devoted to the development of the portable device and the integration of the algorithm in it, as well as to providing robustness to the service against anomalous events such as station or satellite losses or communication dropouts. The portable device is conceived as a demonstrator, and features a processing board which hosts the OS and the algorithms, a communications board integrating the mobile Internet and the Iridium modems, and a touchscreen with a custom user interface for evaluating the solution in real time. On the server side, several instances of the orbit and clock calculation algorithm can be run in parallel for redundancy. A specific piece of software monitors their outputs; in case of problems with the master solution, it switches automatically to another one.

The system is being evaluated under several field scenarios representing many situations that potential users could address in real operations. These include static, kinematic and combined use cases. In the tests, different visibility conditions are evaluated (open sky or different types of obstacles such as trees or walls), as well as the robustness of the solution against communication losses of different durations. The real-time PPP solutions are validated against RTK and/or post-processed PPP.

In this paper we describe the server and client developments undertaken, and we present both the server (i.e. orbit and clock) performances achieved and the resulting positioning performances under the different test scenarios. We also discuss the major challenges faced in all the process, and some ways under research to overcome the limitations of the technique.

PRECISE POINT POSITIONING

PPP is a position location process which performs precise position determination using ionosphere-free measurements, obtained from the combination of undifferenced, dual-frequency observations coming from a single GNSS receiver, together with detailed physical models and corrections, and precise GNSS orbit and clock products calculated beforehand (for example products from IGS, the International GNSS Service [1]). The quality of the reference orbits and clocks used in PPP is critical, as they are both two important error sources in GNSS positioning.

Apart from observations and precise reference products, PPP algorithm also needs several additional corrections which mitigate systematic effects which lead to centimeter variations in the undifferenced code and phase observations, for example phase wind-up corrections, satellite antenna offsets, station displacements due to tides (earth and oceanic), etc.

At a given epoch, and for a given satellite, the simplified observation equations are presented next:

$$l_P = \rho + c(b_{Rx} - b_{Sat}) + Tr + \varepsilon_P \quad (1)$$
$$l_\emptyset = \rho + c(b_{Rx} - b_{Sat}) + Tr + N\lambda + \varepsilon_\emptyset \quad (2)$$

Where:

l_P is the ionosphere-free combination of L1 and L2 pseudoranges

$l\phi$ is the ionosphere-free combination of L1 and L2 carrier phases

b_{Rx} is the receiver clock offset from the reference (GPS) time

b_{Sat} is the satellite clock offset from the reference (GPS) time

c is the vacuum speed of light

Tr is the signal path delay due to the troposphere

λ is the carrier combination wavelength

N is the ambiguity of the carrier-phase ionosphere-free combination (it is not an integer number)

ε_P and ε_ϕ are the measurement noise components, including multipath and other effects

ρ is the geometrical range between the satellite and the receiver, computed as a function of the satellite (x_{Sat}, y_{Sat}, z_{Sat}) and receiver (x_{Rx}, y_{Rx}, z_{Rx}) coordinates as:

$$\rho = \sqrt{(x_{Sat} - x_{Rx})^2 + (y_{Sat} - y_{Rx})^2 + (z_{Sat} - z_{Rx})^2} \quad (3)$$

The observations coming from all the satellites are processed together in a process that solves for the different unknowns; the receiver coordinates, phase ambiguity terms, the receiver clock offset and the zenith tropospheric delay.

Most implementations of PPP algorithms use a sequential filter in which the process noise for the coordinates is adjusted depending on the receiver dynamics, the time evolution of the clock is more or less unconstrained (white noise with a high sigma), and the process noise for the tropospheric delay is adjusted to standard tropospheric activity. In the case of phase ambiguities, they are considered as a constant per pass. This type of filter is required for real-time applications.

Given that PPP is not a differential technique, it cannot resolve integer carrier phase ambiguities (at least, without new enhancements). Hence, it cannot converge to a precise solution in a short time, as other techniques do (RTK, for instance), and requires longer observation times for static positioning.

PPP has been normally conceived as a global service, taking into account that the orbit and clock products are themselves global. This assumption can only be considered valid as long as the tracking network used for the computation of the precise products has worldwide coverage.

Under the previous assumption, good visibility of the satellites along all their orbits can be expected, and the accuracy of the orbit and clock estimations does not depend on the receiver location. This approach may lead to some limitations as there are mainly two options in order to fulfill the global coverage:

1. To deploy a global stations tracking network. This may be complex for political and logistic reasons for example, and possibly too expensive to operate for a regional service provider, whose target may not necessarily be to guarantee a global positioning service.

2. To relay on an external precise orbit and clock product provider. This may limit accuracy, real time capabilities and multisystem approaches. For instance, the IGS products (ultra-rapid, rapid, or final) are widely used due to their known high accuracy, however the IGS does not currently provide GLONASS clocks. Furthermore, official IGS products (IGS Real Time Pilot Project, http://www.rtigs.net/, provide precise ephemeris corrections with few seconds latency) have a latency of several hours, which makes them not valid for real-time PPP.

REFERENCE PRODUCTS FOR PPP

PPP positioning performances are directly related to the accuracy of the reference GNSS orbit and clock products. Therefore, prior to the performance comparison between PPP and RTK, the process followed for the generation of the precise satellite orbits and clocks used in regional PPP will be explained. A complex process as it implies facing the challenge of generating products for a real time PPP service.

For the past years, GMV has been developing an infrastructure for the generation of precise GPS and GLONASS orbits and clocks with very low latency in a first step, and in real time in a second step [2]. A high-level layout of the infrastructure is shown in Figure 1.

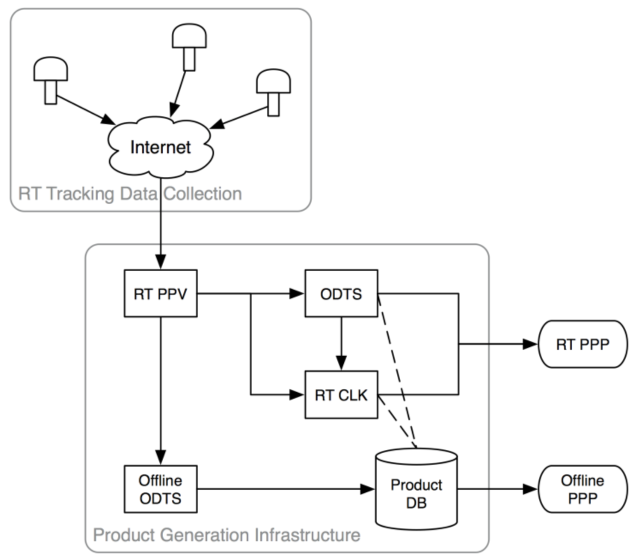

Figure 1 Product Generation Infrastructure High-level Layout

This process retrieves dual-frequency code and phase measurements in real time from a worldwide station network, via Networked Transport of RTCM via Internet Protocol (NTRIP)

Once collected, they are pre-processed also in real time by a Pre-Processing and Validation module (PPV), which then makes iono-free and geometry-free measurements available to the different algorithms.

The reference product generation is based on an Orbit Determination and Time Synchronisation (ODTS) process, which runs every 15 minutes. The ODTS processes 2 days of data in every execution, and provides updated satellite orbits and other estimated parameters (such as phase ambiguities, station tropospheric zenith delays and Earth orientation parameters).

In parallel to the ODTS, another process called RT_CLK estimates the satellite clocks in real time taking as input the pre-processed observations coming from PPV and the outputs from the last ODTS execution. There is a small latency in the delivery of the clock estimate, which is associated to the time that the algorithm waits for the arrival of the measurements from the station through the Internet; typically one or two seconds.

Both GPS and GLONASS satellites are processed together, in order to ensure a consistent solution. It is necessary to estimate an *inter-channel bias* when processing GLONASS data. This must be done in order to compensate for the different internal delays in the pseudorange measurements through the GLONASS receiver, associated to the different frequencies used by the different satellites. Otherwise the station clock estimate would not be coherent with the pseudoranges. It has been observed that in GPS data this effect is much smaller and therefore negligible; normally it is not necessary to estimate such an inter-channel bias for GPS data.

The real-time orbits and clocks are available as a real-time data stream, and stored in standard formats (SP3, clock RINEX) to be used as GPS plus GLONASS reference products for near real-time *magicGNSS* PPP service [3].

The real time orbit and clock reference products are also contributed since 2012 to the Real Time IGS Pilot Project; their performances versus IGS rapid products can be seen in Figure 2. It covers the period since mid 2010 till July 2011.

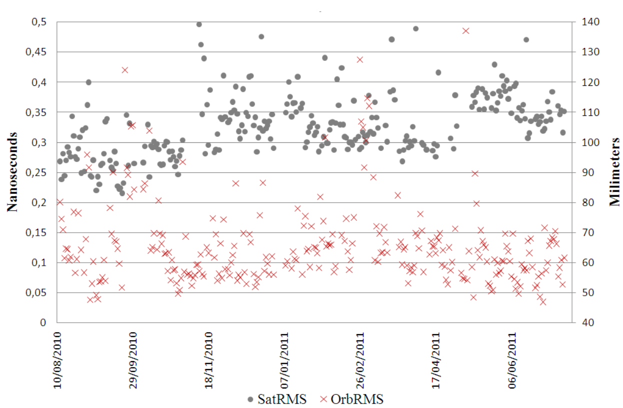

Figure 2 GMV's Real Time products VS IGS

The clock RMS stays around 0.3 ns and the 15-minute prediction orbit error stays around 6 cm.

As it is also represented in Figure 1, there is also an offline ODTS process running in off-line post-processing mode with a latency of 2 days and specific setup, which allows the generation of more precise products than the real time ones. When available, such products are then used for off-line PPP in replacement of the ones generated previously in real time.

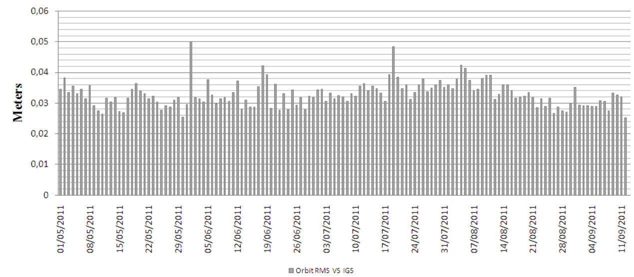

Figure 3 Orbit comparison between IGS products and off-line GPS products for 2011.

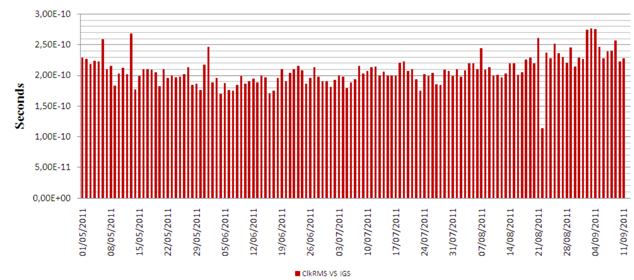

Figure 4 Clock comparison between IGS products and off-line GPS products for 2011.

The comparison of the off-line products with the IGS for a typical day is shown in Figure 3 for orbit and in Figure 4 for clocks. In this case the typical orbit performances are around 3cm, and clock accuracy is around 0.2ns.

The network used, which is represented in Figure 5, provides global coverage and some redundancy to cover the relatively frequent (especially from some stations) outages of the real-time data streams. The different colours indicate the number of stations (also called Depth-of-Coverage or DOC) that are tracking a satellite when it is flying over a particular location.

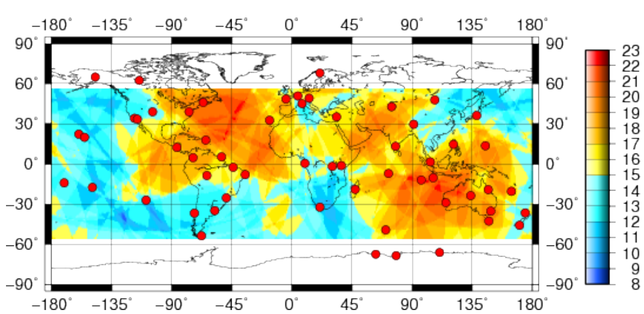

Figure 5 NTRIP Tracking Station Network

Together with the comparison of the off-line reference products with IGS rapid products, their quality is also assured by performing PPP for several IGS stations of known coordinates, over 1 day observation period.

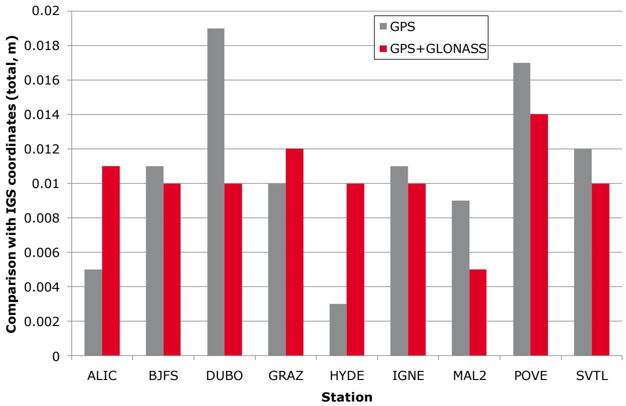

Figure 6 Static PPP Performances VS IGS coordinates (24-hours)

Figure 6 shows the positioning performances for 9 IGS stations with respect to the published IGS coordinates. It can be seen that the accuracy of the PPP solution is around 1 cm, both for GPS and GPS+GLONASS. This result illustrates the good quality of the reference products (both for GPS and for GLONASS) as well as the level of performances of the PPP algorithm.

REAL-TIME PPP DEMONSTRATOR SERVICE

GMV has set up a real-time PPP service for demonstration, called *magicPPP*, built upon the real-time orbit and clock generation infrastructure described earlier. The main objective for this demonstrator is to evaluate real-time PPP performances in the field, in realistic scenarios (both static and kinematic). Being the starting point a consolidated product generation infrastructure, the focus was set on other challenges associated to the end-to-end process, such as communications, robustness and reliability. Another research goal was to learn and overcome the challenges associated to implementing the PPP algorithm in portable devices, in which CPU and memory load as well as power consumption are key issues.

GMV's demonstrator service features a PPP server that accepts connection requests from remote PPP clients, and delivers them the GPS and GLONASS precise orbits and clocks via mobile Internet, or Iridium. In turn, the client accepts observations from a geodetic-class GNSS receiver and processes them together with the products, as described earlier, to produce the positioning solution.

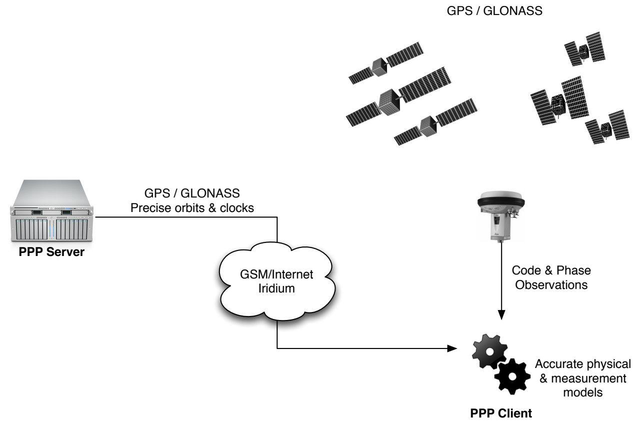

Figure 7 *magicPPP* RT demonstrator service

In order to ensure a high availability, reliability and quality of the real time products used for PPP, several independent computers are running in parallel, in some cases with different configuration and/or data. The corresponding products are monitored for quality and performance, and the best product is selected and sent to the final users. Significant effort has been put not only in the quality check mechanisms but also into the minimization of user impact when a switch between product generation chains is done. When this happens, the user is made aware of the change; the PPP client algorithm is prepared to handle the associated discontinuities in the satellite clocks and GLONASS biases.

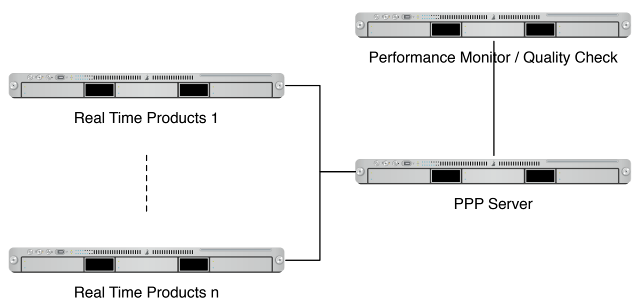

Figure 8 *magicPPP* server redundancy layout

In addition to the generation of high quality products in real time, communications is one of the key drivers for the success of a real time precise positioning application: such products need to be transmitted to the remote users timely and reliably. Therefore, the communications link has to be carefully selected considering bandwidth, reliability, latency, data transfer cost and the required user terminal equipment (modem and antenna, including their cost, size and power consumption). There is a trade-off to be made between the PPP performances (which are affected by the update rate and latency of the corrections) and the cost of the communications (which depends on the required bandwidth).

magicPPP allows testing different communication techniques and some aspects related to the communications having an impact on the final performances. It currently implements two type of communications: mobile Internet or satellite communications using the Iridium Short Burst Data (SBD) service. *magicPPP* can be configured for different transmission rates for the orbit and clock products. The following figure illustrates the major pros and cons of each of the implemented communication techniques.

Mobile Internet	Pros	Cons
	High bandwidth, relatively low cost	Limited coverage
	Cheap modems, good OS support	
	Small antenna	
	Relatively low power consumption	
	Supports 2-way communications	

Iridium SBD	Pros	Cons
	Global coverage	Very limited bandwidth
	Small antenna	Modem cost and integration
	Relatively low power consumption	Latency
	Supports 2-way communications	High cost

Table 1 Communications trade-off

We have performed some trade-offs to evaluate the impact of the PPP transmission data rate and to find the best possible solution. In particular a trade-off between 2-way and 1-way communication has been performed. 2-way communications imply that the client is able to communicate back with the server. This offers a number of advantages:

- It provides a very convenient means to control the access to the service
- It helps speeding up the Time To First Fix (TTFF), by providing the first set of corrections immediately after the connection request is receiver, regardless the update rate of the corrections
- It allows transmitting corrections only for those satellites in view, and consequently brings up a significant reduction in the bandwitdth

However, 2-way communications are not feasible on broadcast-like services (e.g. those which provide the PPP corrections through a GEO satellite).

No matter the link selected for providing the service, two factors affecting the PPP performances need to be considered: latency and update rate. Three different latency components can be described, as illustrated in the following picture:

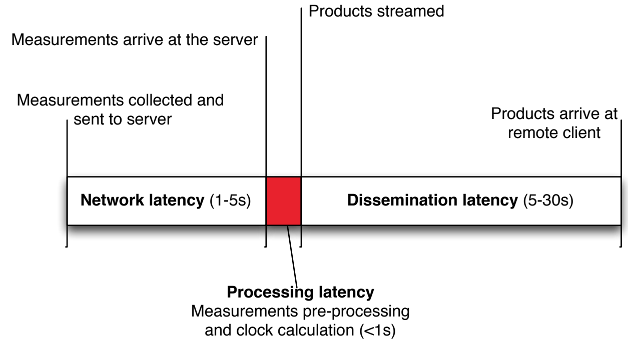

Figure 9 Latency components

- Network latency, the time between the measurements are collected at the tracking station and arrive to the server. *magicPPP* receives NTRIP data from public stations through the Internet, and this time is between 1 and 2 seconds for most sites, although it can exceed it for stations at remote places. The server has a configurable wait time for the measurements to arrive, which is currently set to 5 seconds. Measurements for a given epoch arriving more than 5 seconds later are not used
- Processing latency, the time it takes to pre-process the measurements and calculate the clocks. This is a fraction of a second for our 50-60 stations network and the full GPS+GLONASS constellation
- Dissemination latency, the time between the products are streamed and they arrive to the remote client. This is normally a few seconds when using mobile Internet, but is not less than 30 seconds when using Iridium

The update rate is the rate at which corrections are refreshed (independently of the frequency at which they are computed in the server). The main driver for the update rate is the available (or affordable) bandwidth, and the combination of latency and update rate drives the maximum correction age at the PPP client, as shown in the following picture:

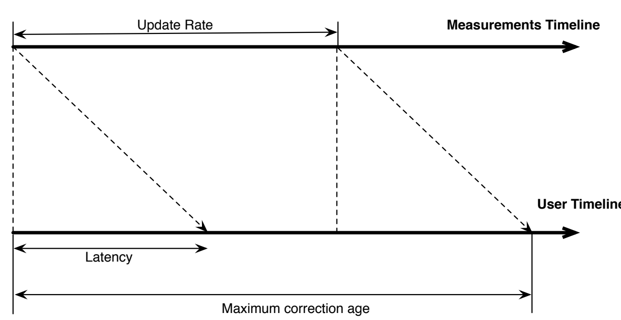

Figure 10 Latency and update rate

The age of the PPP corrections has an impact on the positioning performances. Given that a true real-time (zero age) solution is not feasible, the PPP client has to rely on short-term extrapolation of the corrections to produce the solution. The positioning performances are therefore affected by the predictability of the satellite orbits and clocks.

Orbits can be normally predicted with great accuracy during 15 minutes or even a few hours, since the physics that drive the satellite motion are known to great detail. On the contrary, clock prediction accuracy is highly driven by the satellite clock stability, which presents a certain degree of uncertainty (varying between the different available clock technologies and even on the satellite environmental conditions). Therefore, clock prediction accuracy can degrade significantly after a short period. This suggests that different update rates be configured for orbits and clocks to optimize the bandwidth. Update rates of up to 15 minutes could be reasonable for orbits, yet in this case the TTFF would be unacceptable for 1-way-type services (which could require up to 15 minutes to get the first orbit correction).

The *magicPPP* server allows configuring the orbit and clock update rate independently, and even to set up different values for mobile Internet and Iridium. The following table illustrates the bandwidth in bits per second for different scenarios with our selected message scheme. In all cases corrections to broadcast ephemeris for 56 satellites (GPS & GLONASS) have been considered:

Option	Orb rate	Clk rate	1-way	2-way
High-rate	10s	1s	2554	1463
Low-rate	900s	60s	39	22
Mid-rate	300s	60s	103	81
Mid-rate 2	60s	60s	206	134

Table 2 Real Time PPP data rate (bits per second)

The figures in this table correspond to the current version of the interface, although it is expected that further improvements in the data formatting could result in approximately 20% decrease of the required bandwidth. In any case, the differences between the various choices are significant, which offers a wide range of possibilities to find the required compromise between PPP performances and target communications cost.

As an example, the real-time PPP performances with corrections transmitted at 5-sec (top) and 30-sec (bottom) rate are shown next:

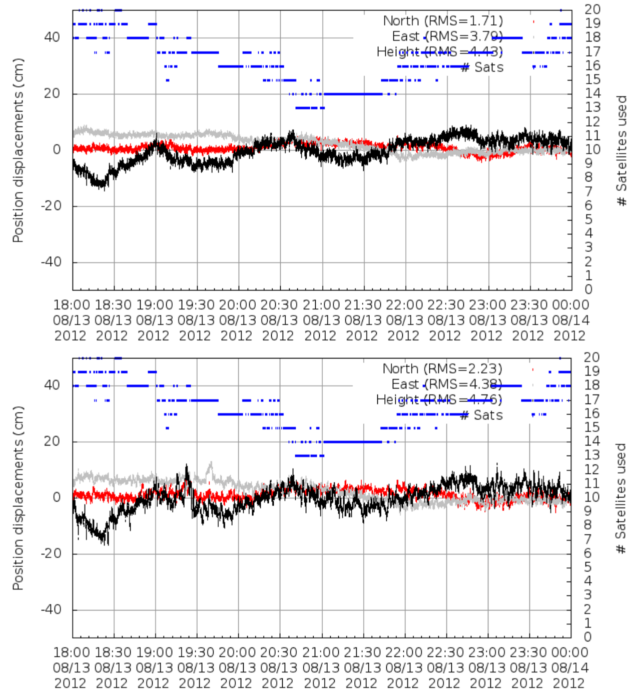

Figure 11 Real Time PPP performances at 5- (top) and 30- (bottom) sec corrections update rate

In this case the degradation is around 15%, although this number depends on the satellites in view and their clocks. *magicPPP* currently delivers orbit and clock corrections at 5-sec rate through the mobile Internet link, which has enough bandwidth either through standard GPRS or 3G networks (and is normally available at affordable flat-rate data plans). It provides orbits at 15-min and clocks at 60-sec rate through Iridium. In this case, clock rates lower than 30 seconds are not worthy (as the latency itself is 30 seconds), and PPP shows a degradation of accuracy around a factor of two versus Internet, at a cost which is not excessive (and yet makes the PPP available virtually everywhere in the world).

Further to the PPP server and its counterpart PPP client software, a portable device has been developed to allow real-time field tests. Of course the PPP client can be run in standard laptops, although the development of the hardware device was carried out to support the integration with satellite communications and to research the ability of the PPP client to run on low-power processing boards with limited computing capabilities.

The device has a processing board with flash storage, that hosts the underlying Linux OS and the PPP client software, a communications board with the mobile Internet and the Iridium modems, a 7” touchscreen and various connectors, as shown in the following figures:

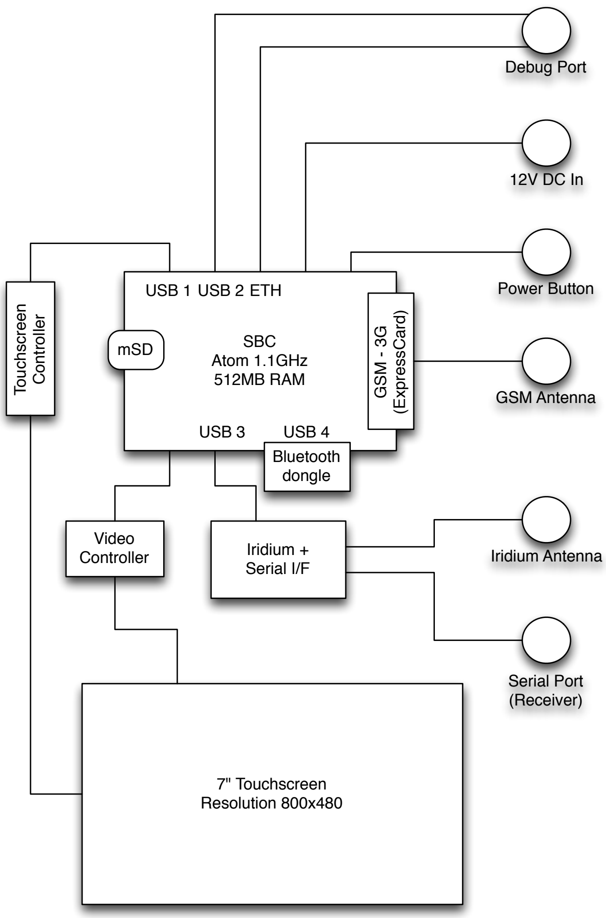

Figure 12 PPP demonstrator - HW layout

Figure 13 PPP demonstrator - HW views

The user equipment features standard connectivity. It connects to any standard geodetic receiver using a serial port, and accepts real-time data in RTCM 3 format, making it work with virtually any modern equipment. The PPP outputs are stored locally for later analysis, and made available in real-time through a Bluetooth port in NMEA format, so they can be input to third-party professional applications running e.g. in a PDA.

It also features a touch-operated user interface for the demonstrations, which allows the user to configure and monitor and control in real time the PPP performances.

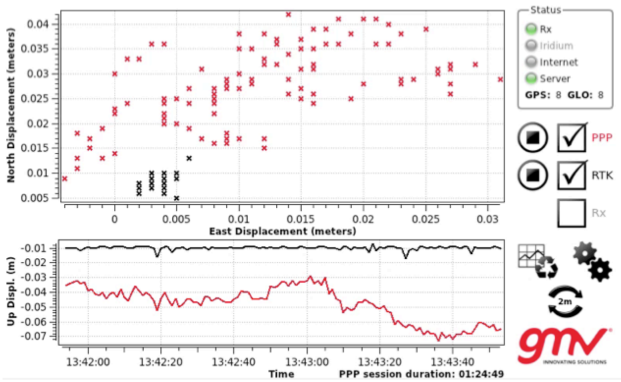

Figure 14 Touch-based user interface

REAL-TIME PPP TESTS

The PPP demonstrator has been extensively tested in different scenarios, both static and kinematic. Further to the positioning performances, which in **Figure 11** are shown to be in line with other PPP implementations available, the main focus has been set on the usability of the system, and therefore its reliability and robustness in real-world field applications.

Most tests have been carried out across a route within a few kilometers away from GMV's premises in Tres Cantos, Spain, which is illustrated next:

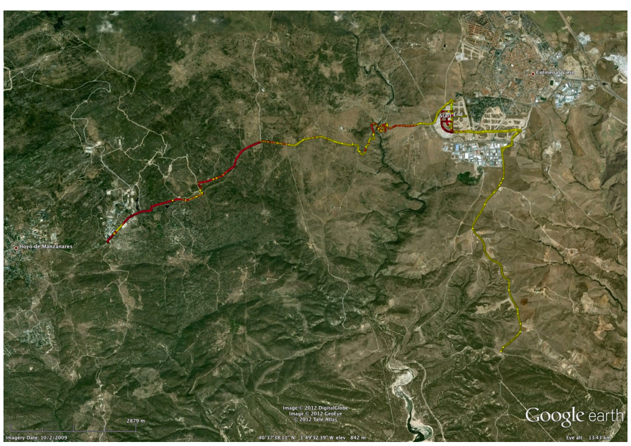

Figure 15 Route for field tests

Kinematic tests are carried out placing a receiver on the roof of a car. Our route stays within 15 km of a base station that can be used for generating reference trajectories using RTK (although RTK sometimes has performance issues at this distance), and allows testing under very different situations: open sky; trees, nearby buildings or other obstacles; and several connection dropouts.

Figure 16 Several test environments

A situation that can affect in-the-field real-time PPP is the temporarily loss of communications with the server, for example when operating far from urban areas or main routes. This implies that the PPP client has to extrapolate the last available correction for up to several minutes, which may not be a problem for the orbits but can affect negatively the clocks. Our test route faces this problem in several points, and therefore some research has been made to improve the algorithm performance in these cases. *magicPPP*'s client is able to withstand dropouts of several minutes by a careful extrapolation of the last satellite clocks and considering the associated uncertainty in a realistic manner. This way, and provided that the algorithm had already converged to good troposphere and ambiguity values (and that not many lines of sight are lost in addition), positioning performances are maintained during a few minutes with very slight degradation, and recovered after the connection with the server is back. An example of the good performances under two forced outages is shown next:

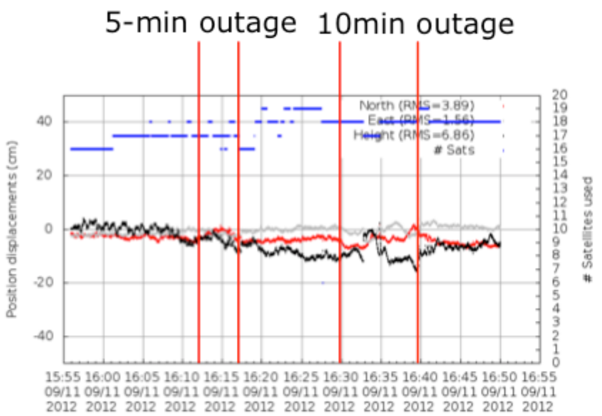

Figure 17 Loss of communications with PPP server

Another situation that compromises field tests is the loss of lines of sight, typically due to nearby trees, buildings or other obstacles. When this happens, the solution degrades due to the lower number of satellites in view (and normally the poorer geometry), and when the lost satellites are recovered, all their ambiguities have to be re-estimated, which results in a certain time to get back to normal performances. Our tests, as already off-line PPP had suggested [4], have shown that the use of GPS and GLONASS is an advantage in these cases, since there are more satellites in view. This helps not only maintain better performances during the outage but also a faster recovery after it.

As an example, the following 2-min track from our test route passes near some buildings (not visible in the picture as it was taken before they were actually built!).

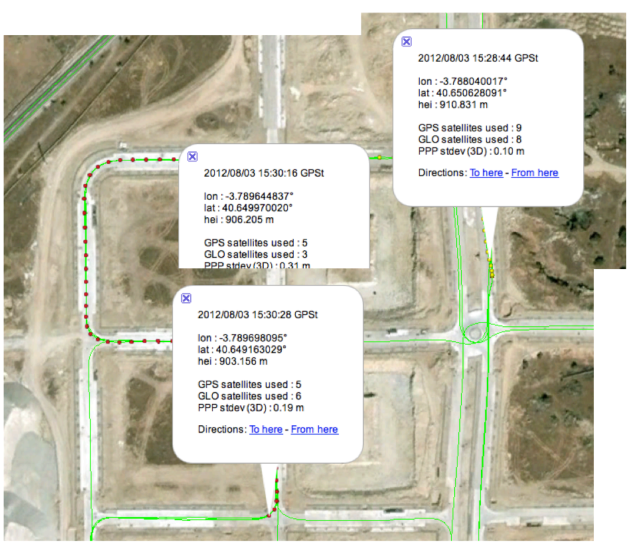

Figure 18 Impact of satellite loss – test trajectory (credits: Google Earth)

The number of satellites at the beginning (top right balloon) is 17, which goes down to 5 GPS + 3 GLONASS at the mid point, and recovers a bit at the end (bottom balloon). Despite that, the performances (as compared to RTK, which by the way is also affected by the loss of lines of sight) do not degrade significantly:

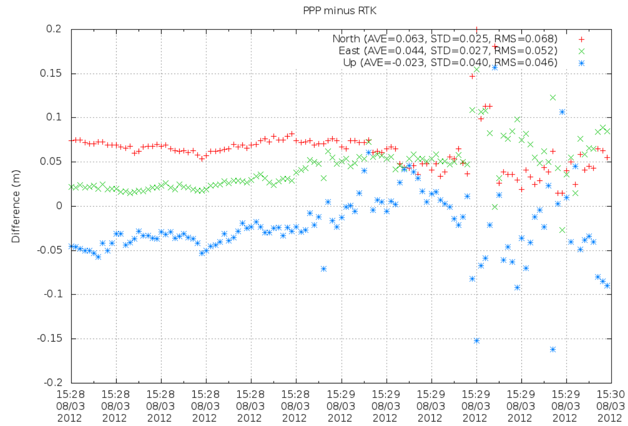

Figure 19 Impact of satellite loss

PPP CONVERGENCE

Convergence is one of the major issues affecting real-time PPP users. The PPP solution takes typically not less than 20 minutes to reach 10-cm horizontal accuracy (RMS), due to the time needed to properly estimate parameters such as the tropospheric delay and the phase ambiguities. While this might not be considered a showstopper for many applications, at least for the start of operations, a 20-min or more re-convergence time after a total loss of satellites is a major issue for field use.

A lot of effort is devoted by several groups to improve the convergence time, which depends on factors such as the initial error and tracking geometry, together with the error in the PPP corrections. Research is made to implement integer ambiguity fixing into PPP, which requires the calibration of several biases, which in turn needs the availability of denser reference networks and additional processing power ant server and client side, as well as some more bandwidth. This makes the advantage versus RTK less evident, and yet yields convergence time still far from the quasi-instantaneous of RTK.

Research is being carried out at GMV on the improvement of the convergence time, including strategies other than the integer ambiguity fixing. As a first approach, a quick start feature has been implemented. This feature yields convergence in a few seconds when the initial position is known within a few centimeters. While this is not a solution for all field users, it is directly applicable e.g. to precision farming, when the tractor is not moved between two consecutive labor days, and therefore the last computed position is valid for quick start. It is also useful to local surveys for civil works, in which one or several points can be calibrated (e.g. a static PPP of several hours) at the beginning of the campaign, and any subsequent measurement run can be quick-started from any of those points.

The following pictures show PPP accuracy without (top) and with (bottom) quickstart. When quickstart is not available, clear convergence patterns are visible, which disappear when a good initial position is known.

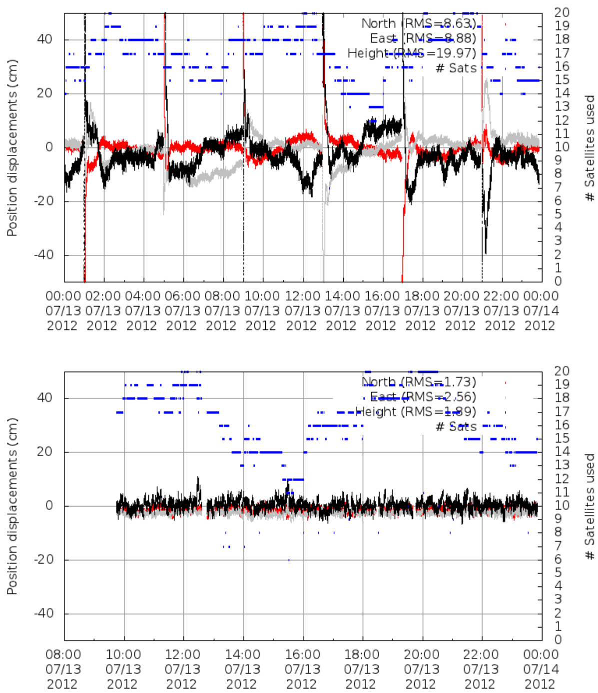

Figure 20 Convergence without (top) and with (bottom) quickstart

CONCLUSIONS AND FUTURE WORK

PPP is coming as an alternative to RTK for many applications. While a lot of research is going on the PPP algorithm, and in particular dealing with the convergence time, real-time field use of PPP faces other challenges that need to be tackled:

- Reliable generation of accurate orbit and clock products in real time
- Communications between the server and the clients
- Overall robustness against many adverse events: product generation chain switches, server outages, satellite outages or high multipath or noise, etc

GMV has developed *magicPPP*, an infrastructure that allows end-to-end field test of PPP in real time, from the generation of the PPP corrections to the end- user algorithm. We have focused on the usability and robustness of the system, and found solutions that help reducing the impact of many events the user will find in field use.

Our future work will try to make the service even more robust, and explore alternatives to deal with the long convergence time of the PPP algorithm. This may include, but will not be limited to, integer ambiguity resolution.

Work is going on, as well, for providing the user with an indication of the accuracy of its solution, in the form of “protection levels”. More information can be found in [5].

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REFERENCES

1. Dow, J.M., Neilan, R. E., and Rizos, C., *The International GNSS Service in a changing landscape of Global Navigation Satellite Systems*, Journal of Geodesy (2009) 83:191–198, DOI: 10.1007/s00190-008-0300-3

2. Píriz, R., Calle, D., Mozo, A., Navarro, P., Rodríguez, D., Tobías, G., *Orbits and Clocks for GLONASS Precise-Point-Positioning*, ION GNSS 2009.

3. R. Píriz, A. Mozo, P. Navarro, D. Rodríguez, *magicGNSS: Precise GNSS Products Out of the Box*, ION GNSS 2008.

4. Laínez, María D. Romay, Miguel M, R. Píriz, A. Mozo: *Multisystem Real Time Precise-Point-Positioning, today with GPS+GLONASS in the near future also with QZSS, Galileo, Compass, IRNSS.* International Symposium on GPS/GNSS, 2010.

5. Laínez, María D. Romay, Miguel M, *Integrity for Advanced Precise Positioning Applications,* ION GNSS 2012