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New Generation of Precise Point Positioning: Exploiting synergies with SIS-based Positioning Augmentation Services

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ABSTRACT

A new Generation Satellite Positioning Augmentation system is being demonstrated in Australia and New Zealand region providing SBAS and Real Time PPP (Precise Point Positioning) capabilities to the service users. The service provision is carried out by Geoscience Australia, Australia's national survey agency, and the Australia and New Zealand CRC SI in research collaboration with industry partners, including Lockheed Martin, Inmarsat and GMV.

The objective of the project is to exploit the potential benefits of satellite navigation technologies, including integrity and high precision applications for all transport and industrial sectors. With this objective a dedicated system has been deployed to experiment and demonstrate the combined SBAS and PPP service through the broadcast of PPP corrections via two SBAS signals by means of a geostationary satellite, and by an internet interface. In the first stage, the service based on a classical SBAS L1 service augmenting GPS constellation. Then, a new generation SBAS DFMC L5 service augmenting GPS and Galileo constellations has been deployed.

The broadcast of PPP corrections through a GEO satellite link has several consequences over the PPP performance. Although it improves the availability of the information, it implies a limitation in the resolution of the PPP corrections. This limitation slightly degrades the achievable accuracy of the PPP solution to a typical RMS user error between 5 and 20 centimetres per direction.

The present paper discusses the Australia Augmentation System technological solution by first describing the combined SBAS+PPP service infrastructure. Second, PPP technologies is described. Finally, preliminary results obtained with the operational service are presented.

This paper shows the feasibility for a PPP service to receive corrections via SBAS service, thus addressing different positioning needs of the users' community by improving availability, and providing accuracy and integrity performances suitable for a wide range of user applications.

BIOGRAPHIES

Cecilia Mezzera holds a Degree in Mathematics from Universidad de la República, Uruguay, specialty in General Relativity, and an MSc in Mathematical Modelling from University College London. When Cecilia Mezzera finished her traineeship in Mission Analysis at ESTEC-ESA, she joined the company as a GNSS engineer working in activities related with magicGNSS, more concretely in precise point positioning and integrity algorithms.

Enrique Carbonell has a Master of Science degree in Aerospace Engineering from the Universidad Politécnica de Valencia (Spain) and Cranfield University (UK). He joined GMV in early 2014 and he has been working in the GNSS business unit designing and developing algorithms and applications. He has emphasized his career on Precise Point Positioning (PPP) and Positioning Integrity algorithms. He started working in the field of High-Accuracy positioning for the Galileo Commercial Service Demonstrator (AALECS) project for the European Commission, and continued his duties in R&D activities related to ionospheric delay estimation for fast PPP convergence. He is currently leading PPP activities both in the ESCAPE project for GSA, and the Satellite-Based Positioning Augmentation Demonstrator for Geoscience Australia.

Borja Torres Minaya holds a Degree in Aerospace Engineering, specialty in Aerospace Vehicles, and an MSc in Space Systems from Technical University of Madrid. When Borja Torres finished his internship in GMV, he joined the company as a GNSS engineer working in activities related with magicGNSS, more concretely in magicPPP services, precise point positioning and integrity algorithms.

Miguel González Calvo holds a Degree in Aerospace Engineering, specialization in aircraft systems and air traffic management from Technical University of Madrid. Currently studying an RF and signal treatment master at the same university. He has worked at GMV in activities related with Precise Point Positioning, RF measurements and market research, as well as implementing several communication protocols.

J. David Calle holds a Master of Science in Computer Engineering from the University of Salamanca. He joined GMV in 2008 and he has been working in the GNSS business unit involved in the design and development of GNSS algorithms, applications and systems. He is currently Head of GNSS Services Section coordinating the activities related to the Galileo Commercial Service, Open Service Authentication and High Accuracy service provision.

Julián Barrios holds a M.Sc. degree in Physics from the University of Valladolid. Since 2007, he has worked at GMV in the Advanced System division within the GNSS Business Unit. Along these years he has acquired an extensive experience into SBAS system through its participation into SBAS demonstrations and experimentations. He has taken part into magicSBAS developments and evolutions to cover different service areas (South America, South Africa, Australia and New Zealand, Korea and Europe). He has also collaborated with ESA EGNOS testbeds including SPEED and HISTB. His activities have been mainly focused into processing chains architecture and interfaces as well as SBAS algorithms enhancement.

Guillermo Fernández Serrano received his MSc. in Telecommunications Engineering from the Technical University of Madrid (UPM) in 2011. He joined GMV in 2011 and, since then, he has been working on activities related to GNSS systems, specifically in GNSS SBAS demonstrators and SBAS algorithm development.

1. INTRODUCTION

Precise Point Positioning (PPP) is a consolidated high precision positioning technique providing centimetre-level accuracy. PPP processes dual-frequency pseudorange and carrier-phase measurements from a single user receiver, using detailed physical models and precise GNSS orbit & clock products calculated beforehand. PPP provides absolute positioning as opposed to relative techniques such as RTK (Real Time Kinematics), which can be a great advantage for many applications.

During 2017 and 2018, a new Generation Satellite Positioning Augmentation system is being demonstrated in Australia and New Zealand providing SBAS and Real Time PPP (Precise Point Positioning) capabilities to the service users. With this objective, a dedicated system has been deployed to experiment and demonstrate the combined SBAS and PPP service through the broadcast of PPP corrections via two SBAS signals by means of a geostationary satellite and by an internet interface. The broadcast of PPP corrections through a GEO satellite link maximizes the service availability in remote areas and maritime environments but it also introduces limitations due to the bandwidth available. On the other hand, the internet-based links are more robust and reliable in urban areas and harsh conditions where the GEO signals might be blocked by existing obstacles.

This paper first introduces the PPP technique concept and how the synergies with SBAS are exploited. Then the user terminal specifically developed for this services is described. Subsequently, a series of relevant field tests in both static and kinematic modes, and making use of different PPP data dissemination means are presented. Test results show centimetric to decimetric positioning solution and protection levels for open-sky and urban environments, being those slightly higher when using the GEO transmission due to the link nature. The convergence period is also analysed for the different solutions. In this analysis the integrity of the protection levels remain unchanged, thus proving that the algorithm is capable of adapting its behaviour to the different conditions and still provide safe protection levels for both vertical and horizontal errors.

2. THE PPP TECHNIQUE AND *magicPPP*

PPP is an advance navigation technique which performs precise positioning determination using dual-frequency or single frequency observations. Observations, which are provided by a single GNSS receiver, are introduced in the PPP algorithm together with advance physical models and accurate GNSS orbits and clocks. GMV has developed a proprietary end-to-end PPP solution, *magicPPP* [5], which covers from the accurate GNSS orbits and clocks generation and data dissemination, to the user algorithm.

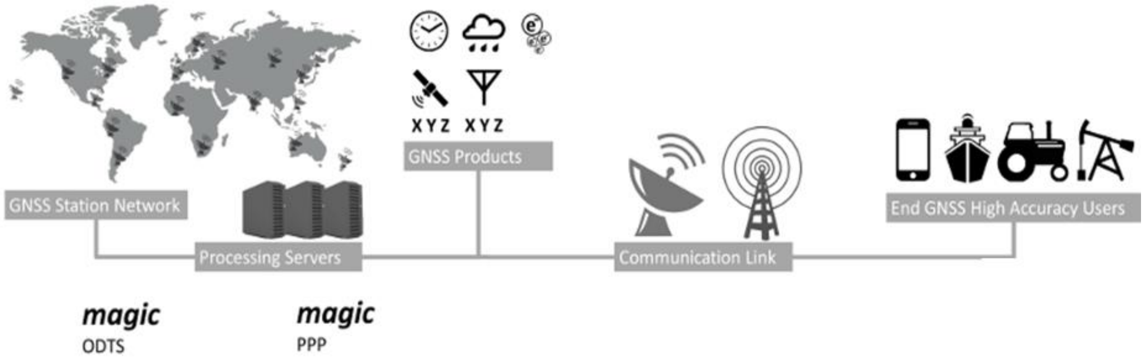

Figure 1: End-to-end PPP chain

The reference product generation used by the PPP service is based on an Orbit Determination and Time Synchronisation (ODTS) process. GMV's proprietary tool in charge of this process is *magicODTS*. This module retrieves multi-constellation, dual-frequency code and phase measurements in real time from a worldwide station network to feed the estimation algorithms. The estimation process runs in a 1-second basis producing real time corrections with centimetre accuracy both for the satellite orbit and clock. The performance of real-time products with respect to IGS for GPS satellites is typically 4 centimetres RMS for the orbit, and 3-4 cm for the sigma clock.

PPP user solution relies on the accurate orbits and clock data. This data may be provided by different means, such as GEO satellite link, radio-link, communication satellites or land-based internet. The user algorithm achieves a horizontal accuracy below 5 centimetres RMS and vertical below 7 centimetres in open-sky conditions.

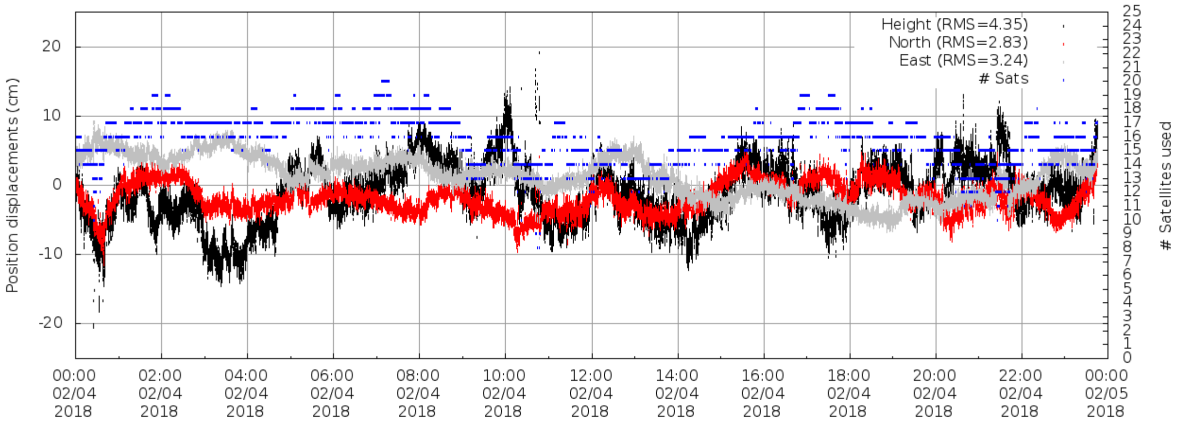

Figure 2: 1 day PPP solution for a GNSS station monitored

PPP user terminal also includes an integrity algorithm able to derive error bounds called Protection Levels (PLs) for different target integrity risks. This KIPL algorithm (Kalman Integrated Protection Level) produces tight integrity-based protection levels to the positioning error based on a mathematically sound algorithm tailored to PPP. One of the main features of this integrity approach is that it combines information from the system and information from the user such as the quality of the received signal or the geometry of the problem in real time.

3. COMBINATION OF PPP & SBAS SERVICES

In the frame of the second generation augmentation testbed in Australia and New Zealand, one of main objectives is the provision of a combined SBAS & PPP service through the Inmarsat GEO satellite. The service deployment has been scheduled in two stages, first demonstrating the feasibility to use the SBAS L1 signal for PPP purposes, and in the second stage using the L5 signals for SBAS DFMC and PPP services. After setting up the services, an experimentation phase organized by Geoscience Australia and CRC SI aiming at assessing the end-user navigation performances utilizing both SBAS and PPP is being executed.

First generation SBAS L1 technology is primarily designed and implemented to support regional aviation procedures with stringent integrity requirements. SBAS L1 messages include both satellite and ionosphere corrections together with the corresponding integrity information.

For the SBAS L5 DFMC, the ionospheric corrections are not required since the users get rid of the ionospheric contribution using the ionospheric-free combination. This opens the door to employ the freed bandwidth to augment new constellations or provide new services, such as PPP.

The technical solution followed for SBAS L1 and L5 services has been the injection of PPP data in the signals following in both cases the requirements for SBAS systems; this ensures the compatibility for end-users. The following key drivers have been considered for the service deployment:

- Provision of a state-of-the-art SBAS service compliance with the standard for L1 and L5.

- The PPP service shall provide real time corrections to reconstruct satellite ephemeris and clocks at the centimetre level.

- When broadcasting the SBAS signal, the service provider has the capability of using message spare bits or additional messages so that the extended corrections can be transmitted. In this configuration, the SBAS users shall continue using the standard SBAS message and ignore the additional bits, but PPP users are able to use this additional information to obtain the real time PPP corrections.

The broadcasting of PPP corrections through a GEO satellite link improves the availability of the signal in remote areas and offshore. Nevertheless, the limited bandwidth available implies a slight degradation the data accuracy and refreshing rate. Typical degradation observed is 1.8-2.0 centimetres per direction which may affect PPP convergence and accuracy performances.

As a complementary service for the test-bed, an internet gateway has been established supporting to protocols, SISNET which reproduces exactly the same information the GEO is broadcasting, and a PPP data provision protocol based on RTCM with higher resolution and refresh time to assess the maximum performance for PPP.

4. SBAS & PPP USER TERMINAL

Dedicated user terminals have been designed and developed to exploit both SBAS and PPP services. The development included two generations of devices, the first generation is a flexible prototype with a set of interconnected elements and the second one is a compact hand-held device.

- **First generation:** A SW receiver based on GMV’s proprietary SRX-10 software [6] is used to acquire and decode the SBAS L1 or SBAS L5 broadcast messages. GNSS observables are gathered by a COTS receiver. Both SBAS and GNSS information is processed in a dedicated device by *magicGEMINI* [9] and *magicPPP* [5] user applications.

- **New generation:** A new hand-held user terminal has been designed and developed using an all-in-one philosophy. It integrates a COTS receiver supporting GPS L1/L2/L5, Galileo E1/E5 and SBAS L1/L5. The terminal hosts an Android operating system where the *magicPPP* [5] application and SBAS user terminal are executed. The device includes different connectivity solution, supporting USB, Wifi, 3G and Bluetooth to choose the most appropriate augmentation solution for the user purposes, GEO, SISNET or PPP.

Figure 3: GMV SBAS and PPP user terminal

The output product is the GNSS receiver trajectory and protection-levels, available as an NMEA stream in real-time and in column-based file for posterior analysis. The positioning solution is shown to the user in the application interface, along with other navigation plots such as satellite status information, C/N0 charts, sky-plot, protection levels, etc.

G01	G02	G03	G04
G05	G06	G07	G08
G09	G10	G11	G12
G13	G14	G15	G16
G17	G18	G19	G20
G21	G22	G23	G24
G25	G26	G27	G28
G29	G30	G31	G32

☐ No obsevations av.
🟥 Observations av.
🟨 Obs. and navigation av.
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Statistics. Last update: 12:33:56 AM

Figure 4: GMV SBAS and PPP user terminal

5. EXPERIMENTATION CAMPAING

In order to demonstrate and assess the performances of the PPP service through SBAS and internet, a set of static and kinematic tests have been executed. The results are presented hereinafter.

5.1 Static tests

The aim of the static tests is twofold, first to analyse the convergence time in the different working modes, and once the algorithm has converge to measure the accuracy of the solution in stationary conditions.

Two-hundred PPP runs for each configuration have been executed to accumulate enough results to derive reliable statistics and metrics. The convergence time is calculated analysing a sliding window of 400 seconds. If 95% of the data in the selected window does not satisfy the PPP accuracy threshold (15 centimetres both for horizontal and vertical error), the window is shifted one second forward and the check is executed again. This iterative process is repeated until the condition is met, and the convergence time is here deducted.

Table 1Table 2 shows the convergence time statistics for PPP though SBAS and internet. Results show how the limitation imposed by the channel impact not only affects the accuracy but also the convergence time.

Table 1: Convergence statistics

Convergence Time	Mean (min)	Max (min)	Min (min)	Median (min)	StDev (min)
PPP Through internet	33.93	92.33	6.70	28.03	20.95
PPP Through SBAS	58.38	225.95	9.74	29.82	60.52

It is important to remark that the convergence time is strictly related to the error thresholds defined to achieve the convergence. These thresholds definitions have to be customized in line with the requirements of the application in question. Next figure depicts the time of convergence evolution for the horizontal axis for the internet-based configuration.

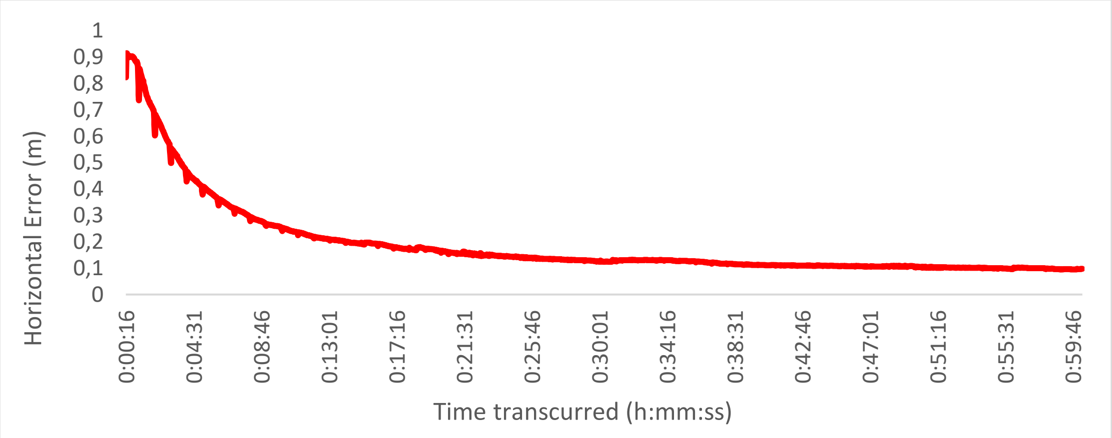

Figure 5: Convergence time visualization

Table 2 shows the RMS errors for both PPP data transmission configurations. It can be observed that a figures are worse in the case of the SBAS data transmission than in the internet option.

Table 2: Accuracy statistics

	RMS North (m)	RMS East (m)	RMS Height (m)
PPP Through internet	0.0353	0.0569	0.0713
PPP Through SBAS	0.1201	0.1740	0.2259

4.2 Kinematic tests

Several Kinematic tests have been performed to cover different user conditions and dynamics and to measure the performances of PPP solutions for both transmission configurations.

GMV’s logo test

This kinematic test was performed at the GMV headquarters on 29th January 2018. The test consists in reproducing GMV´s logo which is written on the ground. A Novatel Vexxis antenna has been used to feed two PPP user terminals. One of the user terminals is configured to use internet augmentation and the second one to use SBAS-like augmentation. The test starts setting the antenna in a calibrated position near the GMV logo and launching the PPP processes. The operator then takes the antenna above his head and walks over the GMV logo. Finally, the antenna is returned to the initial calibrated position.

Figure 6: GMV’s logo test snapshot

Next figure shows the comparison of both PPP solutions, the one augmented through internet (green dots) and the one augmented using the SBAS messages (grey dots). The difference between the two trajectories can be observed in Figure 7.

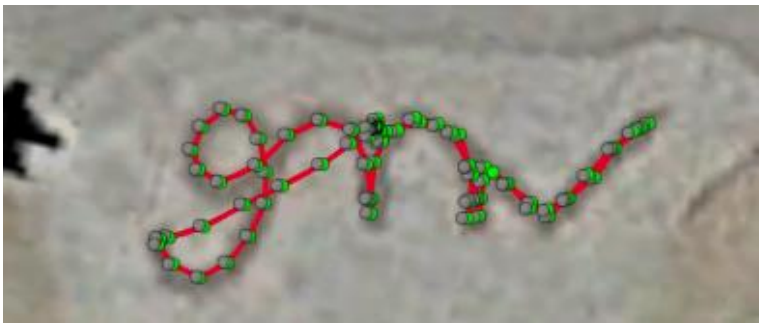

Figure 7: GMV’s logo test solution.

A quantitative comparison between the two trajectories in the North and East directions can be observed in Figure 8. A high-consistency is achieved between the PPP and the SBAS-PPP solutions in both directions, being the RMS error between them 4.30cm and 8.53cm in the East and North directions respectively.

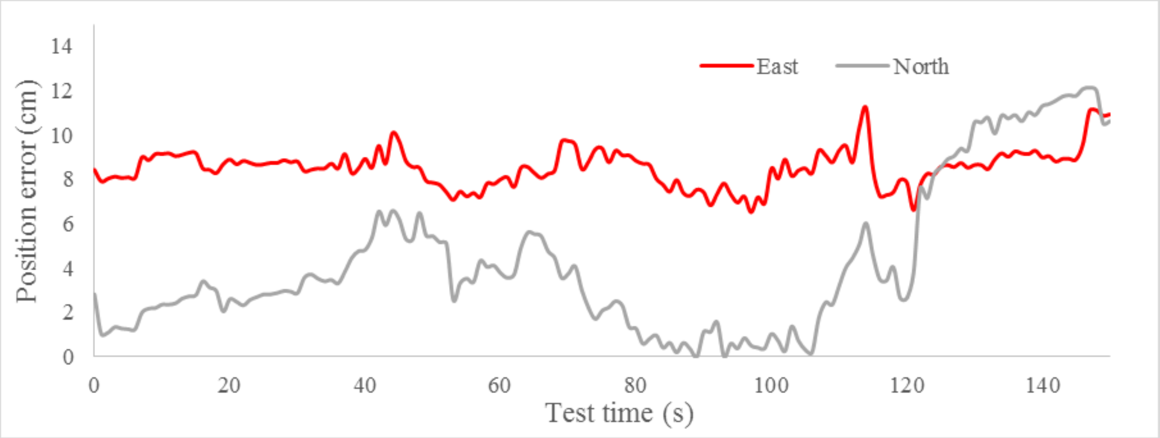

Figure 8: GMV's test horizontal error, measuring PPP via internet versus PPP via SBAS.

Urban test

This kinematic test was performed in Tres Cantos (Spain) on 30th January 2018. To perform the test a Novatel Vexxis antenna was installed in a car roof and connected to two User Terminals. Again the PPP through SBAS and a PPP through internet processes were executed simultaneously. The test consists on an initial quick start followed by an urban trajectory with passes narrow streets with close buildings, under several bridges and high tree foliage areas.

Figure 9: Urban test visualization.

The results of both tests are compared to an RTK solution used as reference. The following table shows the RMS values of the performed tests.

Table 3: Kinematic test results

Category	PPP through internet	PPP through SBAS
RMSE-Horizontal	15.67 cm	17.46 cm
RMSE-Height	14.96 cm	19.89 cm

The results show better accuracy in PPP through internet than in PPP through SBAS. This behaviour is expected because of the degradation of the PPP correction via SBAS.

It is important to note that in urban environments, the RTK solution obtained is degraded in some areas and therefore cannot be used as reference for the overall scenario. The following picture shows the RTK (yellow line) and PPP (red line) solution for a tree canopy environment.

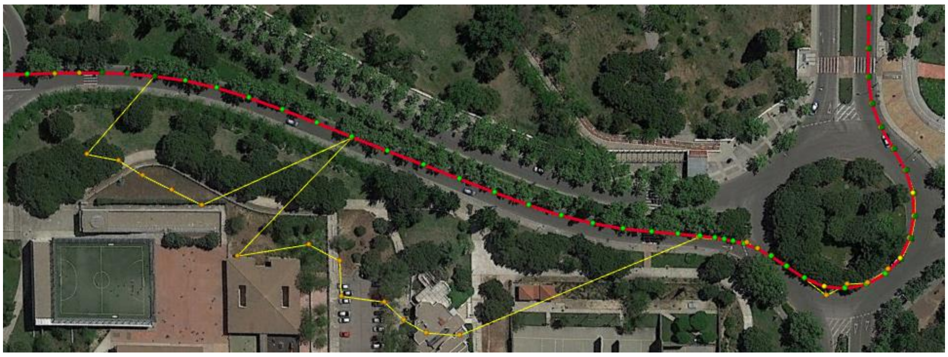

Figure 10: RTK degradation.

Sydney test

A kinematic test was performed on a boat in Sydney, Australia on 06th February 2018. A Novatel Vexxis was used to feed the PPP user terminal.

The test started at Circular Quay, and converged during the trajectory to Rose Bay port. After this maritime journey, the antenna was carried by a user, passing close tall buildings and high tree foliage areas. The user drew an 'SOS' sign on a beach close by and finally, the antenna was returned to the boat and back to the starting point in Circular Quay warf 6.

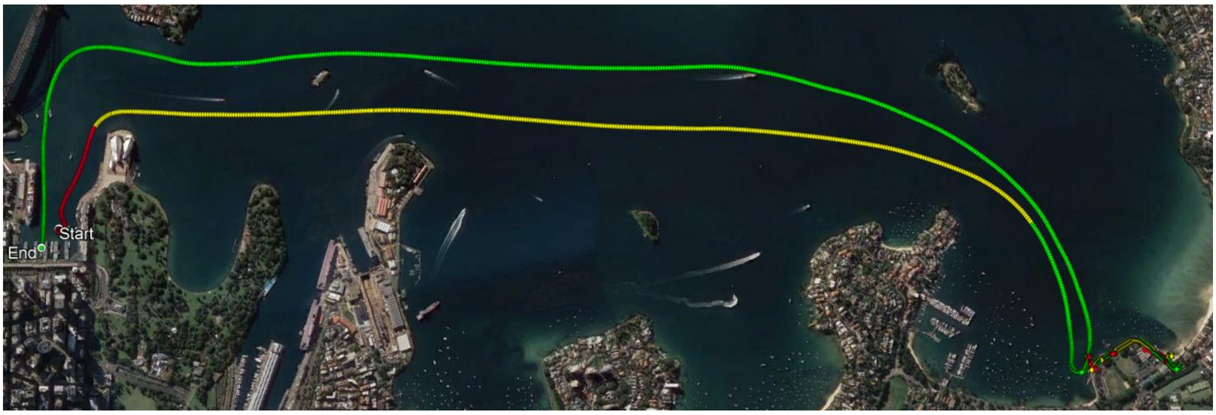

Figure 11: Sydney test visualizations

The PPP solution is nominal during the route, it only loses precision when passing below leafy trees right next to a tall building.

Figure 12: Sydney test 'SOS' trace and test passing near buildings and dense tree canopy

5. CONCLUSIONS

The paper introduces the PPP technique and the specific system deployment carried out for the SBAS second generation test-bed in Australia and New Zealand. The singularities derived of the use of SBAS signals for the PPP data transmission has been revisited, and the strong and weak points of the solution have been identified.

A dedicated experimentation campaign to measure the performances of both PPP solutions has been conducted. The test campaign includes static and kinematic tests to cover different user conditions and dynamics. The results presented show that the convergence time and achievable accuracy is better when using the internet link than with the SBAS data provision. The observed differences are in line with the expected performances due to the limitations imposed by the SBAS GEO link.

6. ACKNOWLEDGEMENTS

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