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G4 Multi-constellation Precise Point Positioning Service for High Accuracy Offshore Navigation

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ABSTRACT: Fugro is operating a global GNSS infrastructure for the delivery of high-accuracy multi-constellation Precise Point Positioning (PPP) service, named G4. Precise orbit and clock for all global satellite navigation systems are estimated in real-time and broadcast to the users using geostationary satellites. End-users with a G4-enabled receiver are able to obtain sub-decimeter positioning accuracy in real-time. The system has been tailored for offshore applications where a nearby GNSS station is not always readily available.
G4 offers seamless integration of GPS, GLONASS, Galileo and BeiDou in the navigation solution, therefore allowing the user to obtain a reliable and accurate position even in challenging environments, especially in presence of interference, scintillation or partial sky visibility. In addition, carrier-phase integer-ambiguity resolution (IAR) is supported, for those users requiring the highest possible navigation accuracy.
This paper presents the G4 system architecture and current performance. The benefits of multi-constellation Precise Point Positioning (PPP) are shown in terms of increased availability, robustness and accuracy.

1 INTRODUCTION

Over the years, Fugro has developed a number of augmentation services for Global Navigation Satellite Systems (GNSS) from code and carrier-phase differential systems to state-of-the-art PPP [1]. Precise Point Positioning [2,3] is based on precise orbit and clock estimates for GNSS satellites together with precise observation modelling at the user-end. The main advantage of PPP with respect to differential positioning is the provision of homogenous accuracy with independence of distance to a reference station, and the need for a less dense reference station network to maintain a given level of position accuracy.

In this context, Fugro introduced in 2009 the G2 service, which was at that time the first global realtime PPP service supporting GPS and GLONASS [4]. Following the GNSS evolution, the system later added support for BeiDou in 2015 and Galileo in 2016, thus becoming a G4 service and supporting all global GNSS systems [5].

In addition, latest advances in PPP technology have shown the possibility to fix so-called carrier phase ambiguities to their integer values, provided that additional corrections (namely Uncalibrated Phase Delays – UPDs – which are hardware delays in the GNSS satellites) are provided to the end-user [6,7]. Fugro is currently generating UPDs for GPS satellites [8], therefore allowing the users to obtain higher levels of position accuracy. G4+ denotes G4 solutions when carrier-phase ambiguities are fixed.

2 GNSS SYSTEMS STATUS

At the time of writing this article, the GPS system is composed of 31 operational satellites, including 12 IIR, 7 IIR-M and 12 IIF satellites. GPS-IIR-M and IIF satellites are transmitting the new enhanced L2C signal, while GPS-IIF are also transmitting a new civil signal on the third frequency L5.

The Glonass system is composed of 24 satellites, mainly Glonass-M satellites, but also including one new generation Glonass-K1 satellite.

In addition, the Chinese system BeiDou is currently composed of 5 Geostationary (GEO), 5 Inclined Geosynchronous (IGSO) and 4 Medium Earth (MEO) orbit satellites. All these satellites were put in orbit by 2012. In addition, China has launched 7 additional satellites in 2015 and 2016, but these are not considered part of the operational constellation yet.

Last but not least, the Galileo system was declared ready for operational use on December 15th 2016. In January 2017, the system consists of 11 usable satellites, including 3 IOV (In Orbit Validation) and 8 FOC (Full Operational Capability) satellites. Additionally, there is one IOV satellite (E20) which is only transmitting on E1 frequency, and cannot be used for dual-frequency PPP. Two additional satellites were placed in elliptic orbits after a launch failure in 2014 (PRNs E14 and E18). These satellites started to broadcast test ephemeris in 2016, although they are still reported as unhealthy. Finally, four additional satellites (E03, E04, E05 and E07) were launched in November 2016 and are under commissioning at the time of writing this article.

Therefore, the G4 service currently generates corrections for over 80 satellites and it is expected that it will support about 115 satellites in 2020 once BeiDou and Galileo constellations are fully deployed. G4 offers seamless integration of all satellite systems to deliver a robust solution for the end-user.

3 G4 SYSTEM ARCHITECTURE

The G4 system high-level architecture is depicted in Figure 1. The G4 network consists of 45 multi-GNSS reference tracking stations, worldwide distributed (Figure 2). For redundancy reasons, two different receiver brands are used in the network. This guarantees system continuity should an anomaly appear in one of the receiver brands.

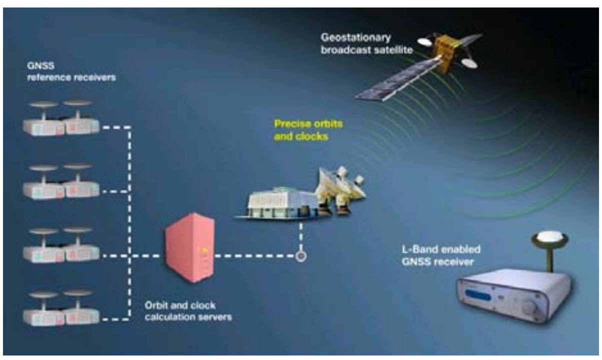

Figure 1. G4 system architecture

Real-time observation and navigation data is sent to the processing centres, located in Norway, which are in charge of estimating real-time orbit and clock estimates for all GNSS satellites. These are then forwarded simultaneously to two Network Control Centres (NCCs), located in Houston (USA) and Perth (Australia). The NCCs generate the final correction streams (including UPDs) and broadcast them to the users via eight geostationary satellites, whose coverage is depicted in Figure 2.

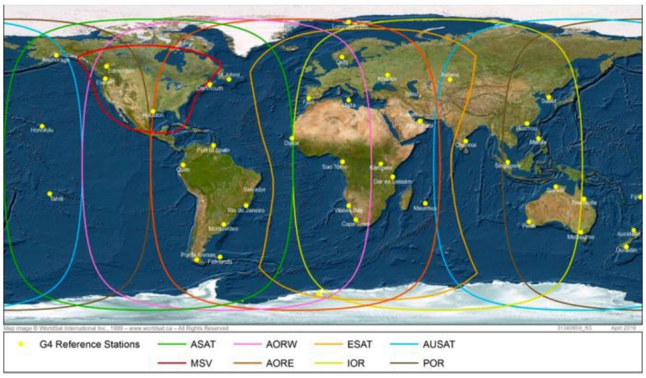

Figure 2. G4 tracking network and coverage area for geostationary satellites

At any given location below about 75° latitude, the user can typically observe two geostationary satellites simultaneously. Corrections are broadcast in L-band and can be received via standard GNSS antennas. At the user end, Fugro-enabled receivers can decode the L-band correction signal and, using Fugro's proprietary PPP processing engine, obtain high-accuracy real-time positioning.

The system has been designed with significant levels of redundancy, in order to avoid any end-to-end single point of failure and meet high availability requirements for offshore navigation and operations.

4 GALILEO ACTIVATION

As described in section 2, the Galileo system has been developed significantly in the last years, and Initial Services were declared on December 15th, 2016. Fugro has been actively preparing for supporting Galileo in its PPP service [9], and started to broadcast corrections for the 11 Galileo satellites immediately after Initial Services were declared. Figure 3 shows a display of a G4 solution inside a Fugro 9205 receiver using Galileo corrections broadcast over ESAT satellite on December 15th, 2016.

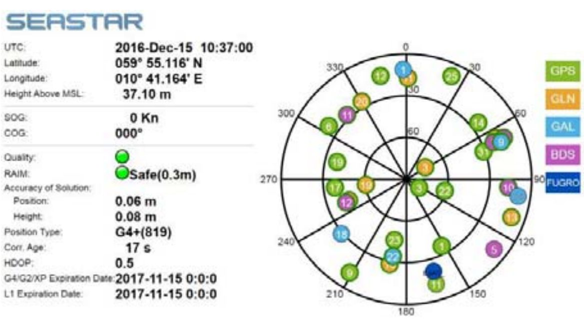

Figure 3. Display of a G4 solution in a Fugro receiver after Galileo activation on December 15th, 2016

5 ACCURACY PERFORMANCE

Figure 4 shows real-time G4 kinematic performance for a stationary receiver located in Oslo on December 15th, 2016. It should be noted that Galileo corrections start contributing to the position solution from 10:30 UTC when the first operational Galileo corrections were broadcast via geostationary satellites.

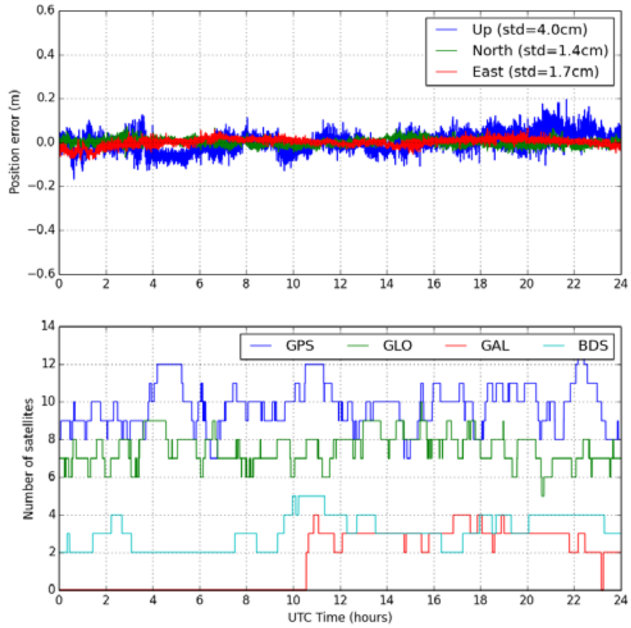

Figure 4. Real-time G4 performance in Oslo on December 15th, 2016

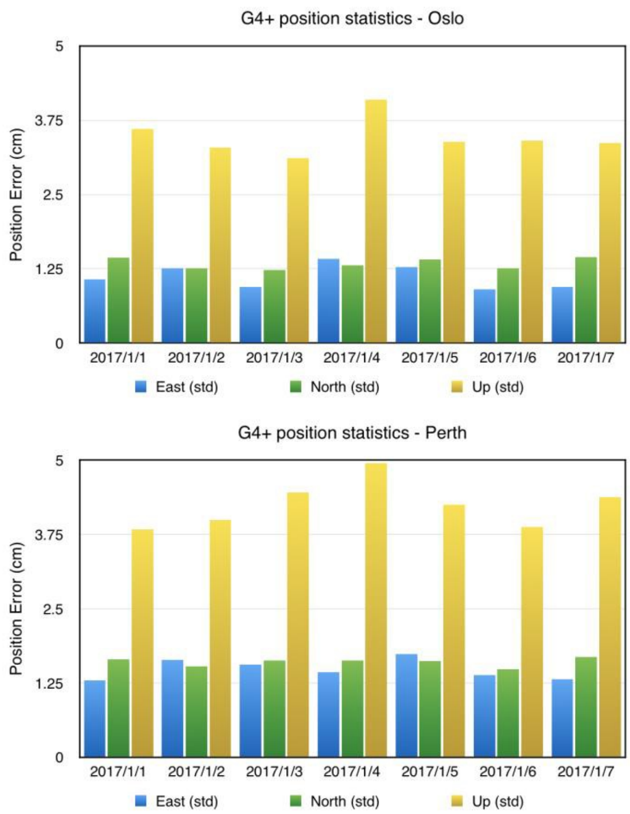

Figure 5. G4 positioning statistics for Oslo and Perth

Figure 5 presents position statistics for Oslo (Norway) and Perth (Australia) for the first week of 2017. It can be observed that position accuracy is very stable and consistent, and horizontal accuracy is about 1.2 cm horizontal and 4.0 cm vertical (1-sigma).

6 KINEMATIC MARITIME POSITIONING

In order to assess G4 performance in a realistic maritime environment, a dual antenna GNSS positioning system has been installed on-board the *Baronen* vessel, a high speed passenger ferry in Oslo fjord (depicted in Figure 6). The vessel is equipped with two GA810 antennas, each of them is connected to a Fugro 9205 multi-GNSS receiver. Both on-board receivers have been configured to deliver G4+ solutions, including GPS, GLONASS, Galileo and BeiDou.

Figure 6. *Baronen* vessel including location of GNSS antennas

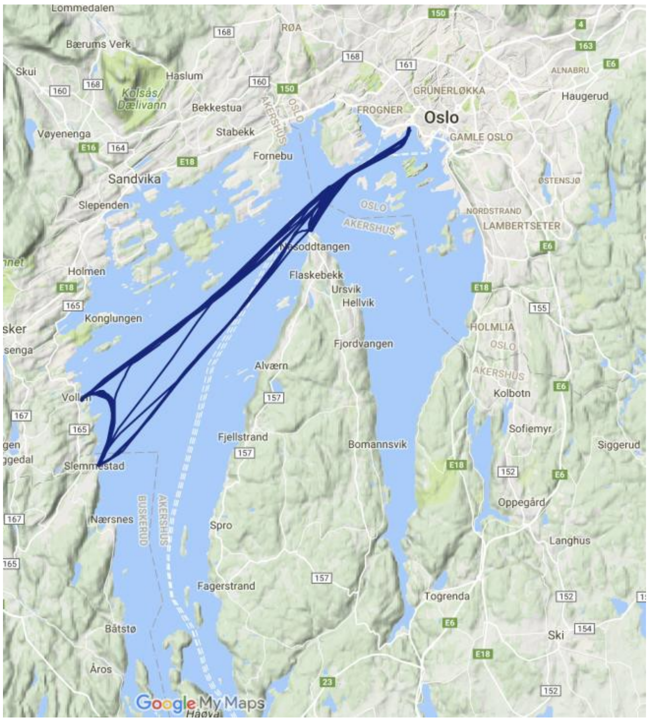

Figure 7. Trajectory of the Baronen vessel on January 14th, 2017

The real-time absolute positions are stored on-board in NMEA format and retrieved routinely for performance assessment. Figure 7 depicts the vessel trajectory in the Oslo fjord on January 14th, 2017. Figure 8 displays the navigation solution for the day under analysis, including antenna heights, measured antenna distance, vessel speed and number of satellites used in the solution. From the speed plot, it can be observed that the vessel is doing short trips between 4-8 UTC and 14-23 UTC. The average cruising speed is about 14 m/s (27 knots). The rest of the time the vessel is docked.

In order to assess the quality of the positioning solution, the baseline (distance) between the two antennas has been computed, by differencing the absolute antenna positions at every epoch. It can be observed that the computed antenna distance is very stable over the whole day, even in the high-dynamic conditions. The standard deviation of the antenna distance is 1.9 cm, for the 24 hours under analysis.

7 MULTI-GNSS BENEFITS

Multi-GNSS PPP solutions deliver higher-levels of accuracy compared to GPS-only solutions due to the increased number of satellites. However, the main benefit of multi-GNSS is increased robustness in case of poor satellite tracking, in cases of partial sky-visibility, ionospheric scintillation or interference. Thanks to additional satellites in view and different frequencies used by different GNSS, multiGNSS solutions perform significantly better in situations with poor signal quality.

As an example, Figure 9 displays signal to noise ratio (SNR) measured by a Fugro monitoring receiver located in Port of Spain (Trinidad and Tobago) on December 29th, 2016. The location was affected by a 20minute long RF interference that impacted significantly the quality of received GNSS signals. In particular, both GPS and GLONASS L1 and L2 bands were affected by about 10 dB. Galileo E1 signal was also affected, and Galileo E5 to a lesser extent. Fugro has observed similar events in other locations and this kind of interference can affect maritime users, causing either total lack of tracking for GNSS satellites or, as in this case, poor signal quality and increased frequency of cycle slips.

In the position domain, figure 10 shows G2 (GPS and GLONASS) and G4 (including Galileo) height error in Port of Spain for the same time span, including also the number of satellites that was used in the PPP solution. It can be observed that at a given moment in time, only three GPS and no GLONAS satellites are usable, and this results in a position reset for the G2 solution.

Thanks to the addition of Galileo, 2-3 additional satellites can be used when the interference appears, and continued good accuracy can be computed during the whole interval, without impact for the end-user. Galileo is particularly useful in these cases as it provides additional frequency redundancy in the E5 band.

8 CONCLUSIONS

Fugro's G4 system represents state-of-the-art Precise Point Positioning technology for off-shore positioning, and it has been proven to deliver outstanding results in both static and dynamic conditions. With the addition of Galileo and BeiDou, navigation users can use today as many GNSS satellites as never before, and this allows unprecedented levels of accuracy, availability and continuity for maritime applications.

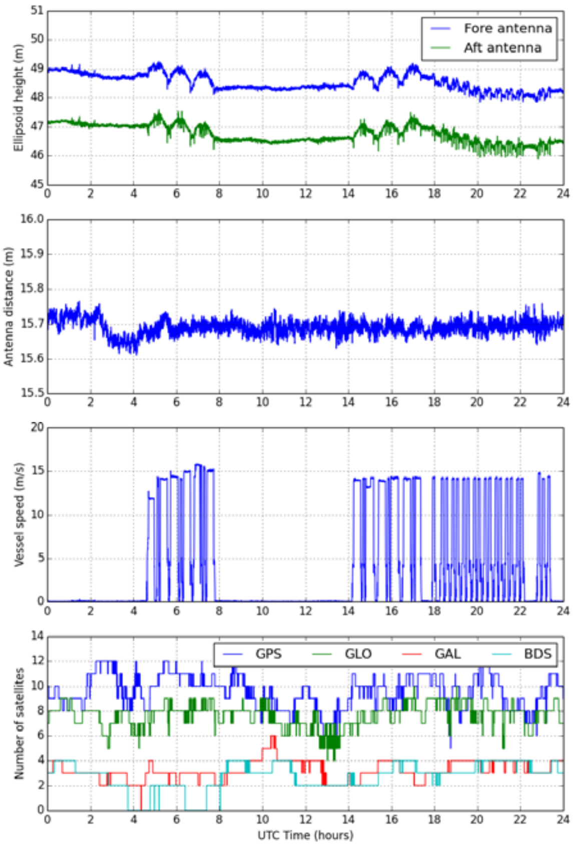

Figure 8. Navigation solution on-board the Baronen vessel

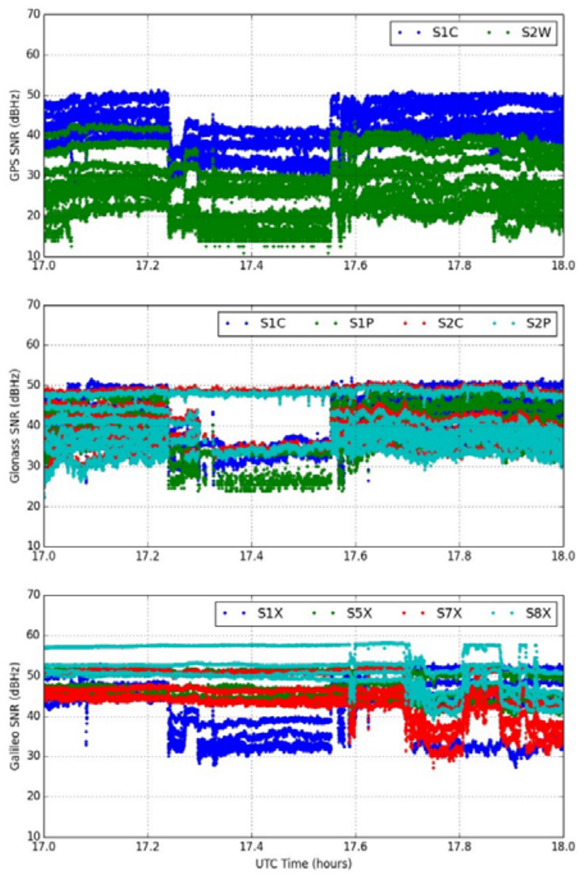

Figure 9. Signal to Noise Ratio (SNR) recorded for different GNSS signals in Port of Spain on December 29th, 2016

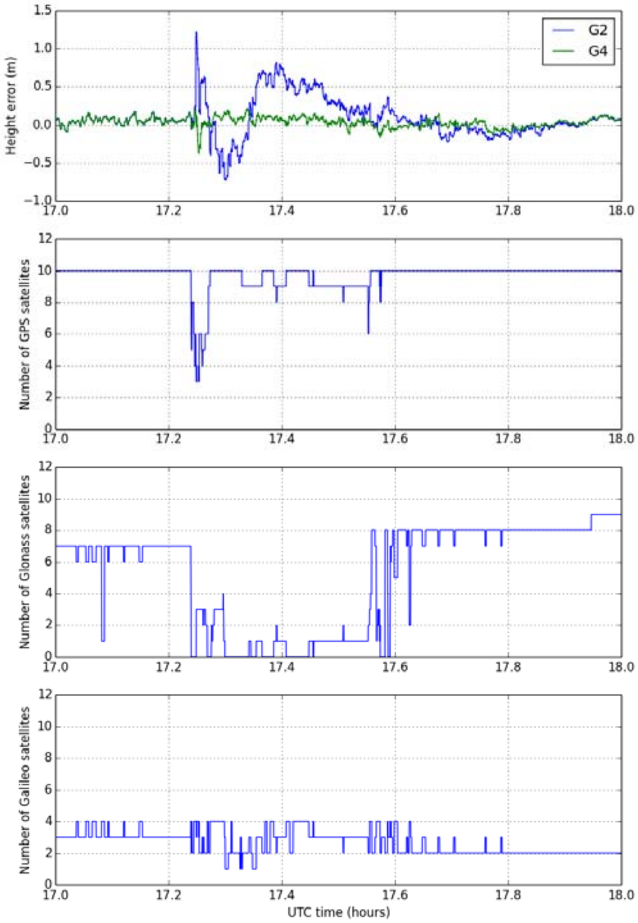

Figure 10. G2 (GPS+GLONASS) and G4 (GPS+GLONASS+Galileo) height accuracy for Port of Spain

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