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USE OF BEIDOU IN OPERATIONAL PRECISE POINT POSITIONING SERVICE

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Abstract

In 2009 Fugro added GLONASS to its operational real-time Precise Point Positioning (PPP) service. Fugro's aim is to introduce additional Global Navigation Satellite System (GNSS) as they become operational. A few years back, the expectation was that the European Galileo system would be the third GNSS system to be introduced in the Fugro PPP service, and Galileo real-time PPP was demonstrated in 2013. Due to delays in both system deployment and declaration of Initial Operational Capability (IOC) for Galileo, this has been postponed in favour of introducing the Chinese BeiDou system.

China has now deployed 13 satellites in their BeiDou system. The current satellite constellation consists of 3 Medium Earth Orbit (MEO) satellites, 5 Inclined Geosynchronous Orbit (IGSO) satellites and 5 Geostationary Orbit (GEO) satellites. Since the IGSO and GEO satellites reside over the Far East region, it is possible to achieve 24 hour coverage for positioning using only BeiDou in that region, where typically 8-12 BeiDou satellites are seen at any time.

In the spring of 2013 Galileo had 4 In Orbit Validation satellites (IOV) transmitting valid signals. Fugro did provide the first Galileo only solution with decimetre level accuracy using its own orbit/clock data generated by its reference station network. This was within a week of the EU/ESA announcing their first Galileo only fix, at the few meter level.

In 2014 further developments were made and BeiDou satellites were introduced into the Fugro PPP processing chain. BeiDou is the first GNSS system to use GEO satellites, and this requires additional tuning in the processing. Examples of positioning with BeiDou will be given, including 24 hour plots of BeiDou only decimetre level positioning including GEO satellites.

Fugro Satellite Positioning is providing GNSS augmentation services for marine/offshore Dynamic Positioning (DP) applications worldwide. DP applications are safety critical and it is important to have access to two or more independent positioning reference systems in order to have high availability and robustness. Today GPS is the basis of most GNSS setups in DP applications, often together with GLONASS. It is accepted as use of two “independent” setups in DP as long as the augmentation data is provided via independent channels. In the future, with four GNSS systems, it will be possible to configure two truly independent setups, each with high availability and robustness, by using two GNSS systems in each setup (e.g. GPS and BeiDou in the first setup and GLONASS and Galileo in the second).

Fugro has now introduced BeiDou in the operational PPP service, and will include Galileo as soon as IOC has been declared for the Galileo system.

Introduction

Precise Point Positioning (PPP) using Global Navigation Satellite Systems (GNSS) accurate Orbit and Clock (O/C) data has become the preferred way to augment GNSS systems for high accuracy in offshore type environments. Such systems rely on a worldwide network of reference stations collecting raw GNSS ranging data. These ranging data are used to calculate accurate satellite orbit and clock errors, which are broadcast to users in real time. In the mobile receivers in the field, dual frequency GNSS phase observations are used in order to achieve better than 10 cm positioning accuracy. Fig 1 depicts the traditional range based Differential DGNSS system and Orbit/Clock PPP systems. The advantage of PPP is that the O/C corrections are valid worldwide and provide homogeneous accuracy, while using Differential GNSS mode a user needs to be in the vicinity of the reference station (1000-2000 km).

Fugro G2 is a commercial service offering real-time PPP based on augmentation of the American GPS and Russian GLONASS [1], targeting maritime high-precision applications. It has been operational since 2009 and it was the first of its kind to include GLONASS. Following the deployment of new satellite systems, such as Galileo and BeiDou, the service is extended with additional GNSS's as they become available.

Since the first European Galileo In Orbit Validation (IOV) satellites were launched in 2011, work has been done to include Galileo in the Fugro PPP service. It is now qualified for supporting Galileo.

In parallel, the Chinese BeiDou GNSS system has been deployed rapidly in the last years, and has at the moment 13 operational satellites, thus becoming an attractive complement to other GNSS for high precision positioning.

In order to accommodate new constellations, Fugro launched the G4 service in February 2015, currently supporting PPP with GPS, GLONASS and BeiDou. G4 is ready for Galileo and will be offered when the satellites are declared operational.

In addition, the G2+ service was launched in March 2015, bringing an enhancement to G2 with ambiguity-resolved PPP, designed for users with high-accuracy requirements at the few centimetre level. Furthermore, Fugro offers an XP2 service, based on orbit and clock from an external provider, using also GPS and GLONASS.

In summary, Fugro PPP services today include:

- G2: GPS/GLONASS, ambiguity-float PPP
- XP2: GPS/GLONASS, ambiguity-float PPP (Independent of G2/G4)
- G2+ : GPS/GLONASS, ambiguity-fixed PPP
- G4: GPS/GLONASS/BeiDou, ambiguity-float PPP (Galileo ready)

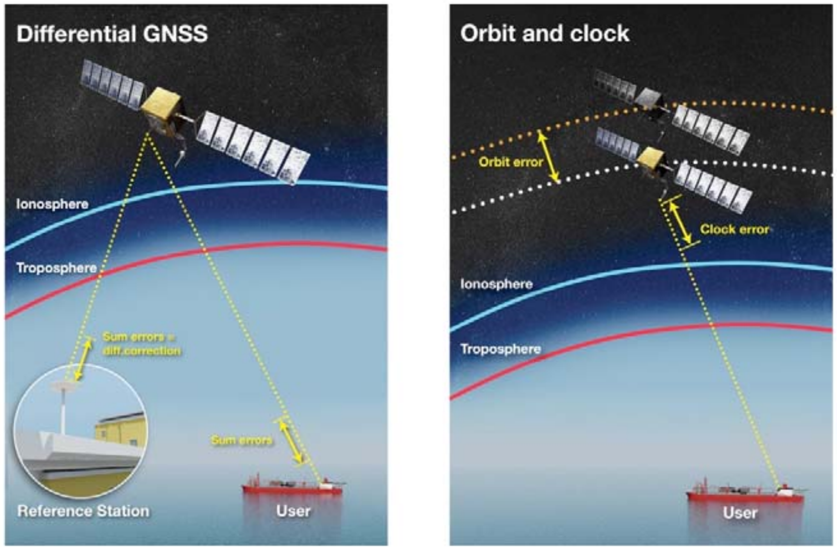

Fig. 1: Traditional Differential GNSS (left) and PPP using orbit and clocks (right)

Galileo PPP development

In the spring of 2013, four Galileo IOV satellites were in orbit and started to transmit navigation messages. At that time Fugro had already deployed a significant number of Galileo capable reference stations around the world, and was capable of calculating Galileo orbits to the decimetre level [2]. This resulted in Fugro being able to calculate a precise Galileo only position using the four satellites within a week after ESA announced its first real-time positioning results based on Galileo signals only.

After this initial success, there were delays in the launch of the first Full Operational Capability (FOC) satellites. When the first Galileo FOC satellites were launched in August 2014, there was another setback as they failed to reach the correct orbit, due to a failure in the upper stage of the Soyuz launcher.

The orbits were corrected to some extent, in December 2014 and March 2015, but the satellites remained in elliptical non-nominal orbits, as shown in Fig 2. At this moment, it is unclear whether the satellites will be part of the operational Galileo constellation. Two additional FOC satellites were launched on March 27, 2015, and two on September 10, 2015. All these four satellites are now under commissioning.

It is now expected that enough Galileo satellites will be in orbit to declare Initial Operational Capability, or “Early Services”, by early 2016. Fugro is ready to add Galileo to the G4 service as soon as this happens. The full 30 satellites Galileo constellation is expected in 2020.

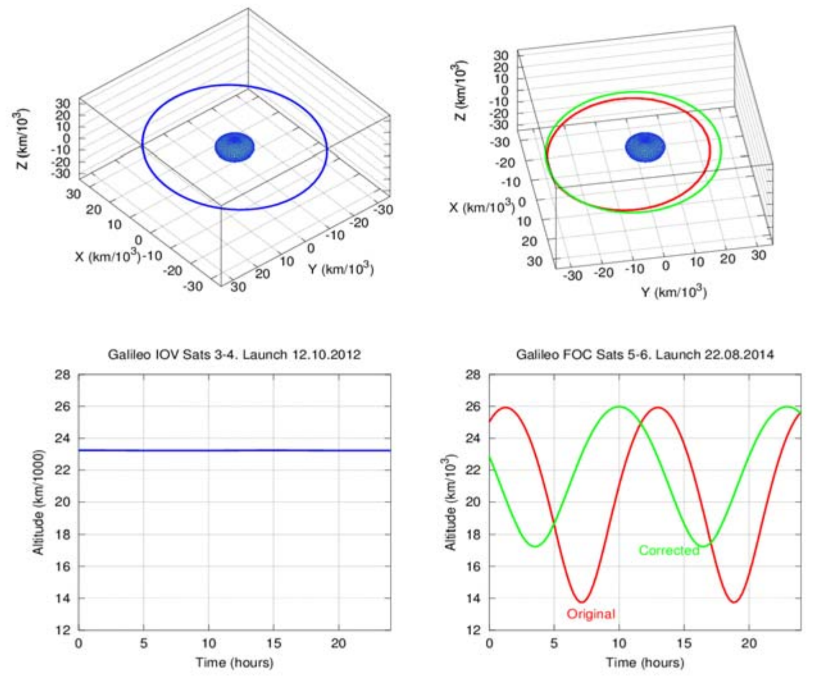

Fig. 2. Nominal (left) and non-nominal orbits (right) reached by the first Galileo FOC satellites.

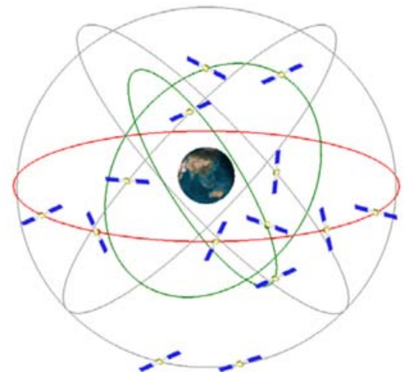

Fig. 3. BeiDou constellation (Source: [3])

BeiDou PPP development

China has developed a GNSS system named BeiDou [3], which in December 2012 reached operational service with a constellation of 14 satellites. By March 2015, the constellation consists of 13 active satellites, with the following configuration:

- 3 MEO satellites (Medium Earth Orbit)
    - Altitude 21500 km, 55 deg inclination
- 5 GEO satellites (Geostationary Orbit)
    - Altitude 35786 km, 0 deg inclination
- 5 IGSO satellites (Inclined Geosynchronous Orbit)
    - Altitude 35786 km, 55 deg inclination

The constellation distribution is shown in Fig 3, and the ground track in Fig 4. Thanks to the 5 IGSO and 5 GEO satellites that reside in the Far East, the system is providing 24/7 positioning in China and neighbouring countries. Fig. 4 shows the geographical area with continuous BeiDou availability (in yellow), with the current constellation. In this region, a minimum of 4 satellites are visible above 10 degrees elevation, with a Dilution of Precision (PDOP) lower than 8. It is expected that the system will provide global coverage when the complete MEO constellation is deployed within 2020.

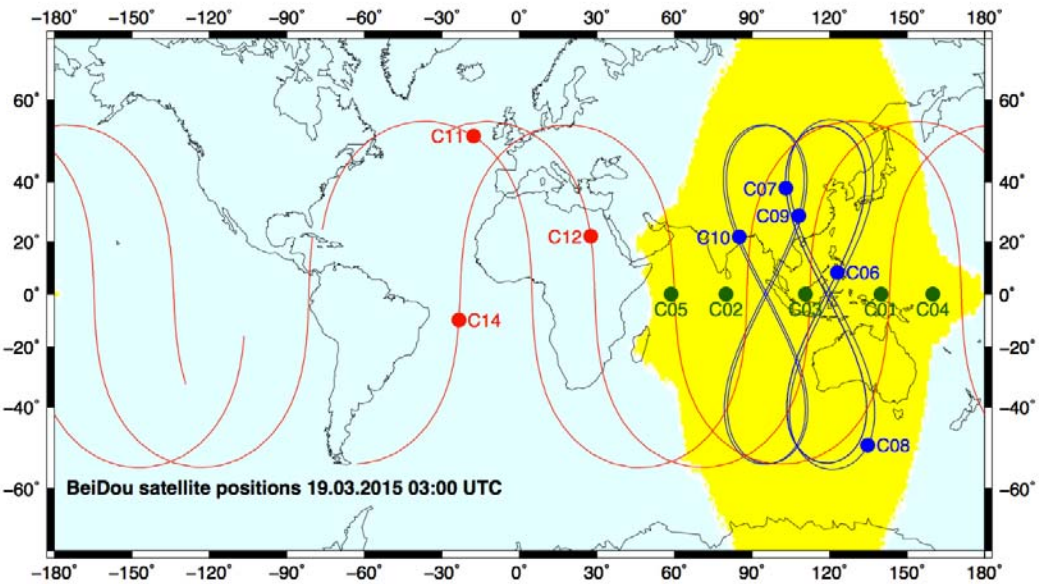

Fig. 4. Ground track for BeiDou satellites and geographical area with BeiDou 24/7 coverage (PDOP<8)

One of the challenges associated with BeiDou PPP is the generation of precise orbits for the GEO satellites. These satellites follow a different satellite orientation (attitude) than the one used by other GNSS satellites in MEO orbits. In addition, the satellite geometry with respect to the ground network is almost constant, and this lack of geometry variation imposes some limitation in the obtained accuracy. Currently, the achieved orbit accuracy for GEO satellites is roughly three times worse than for MEO and IGSO satellites. On the other hand, estimated satellite clocks can partially absorb the orbit radial errors, and along- and cross-track errors do not directly translate into user range errors. For these reasons, GEO satellites can still be used for PPP, albeit with lower accuracy than for MEO and IGSO satellites.

Even if the main coverage is in the Far East, there are a number of satellites available for use in other parts of the world that may be used in combination with GPS and GLONASS. Fig. 5 shows a prediction using reference [5] for the number of visible BeiDou satellites for selected places around the world. It should be noted that in Europe (Oslo) and West Africa (Douala) there are up to 6 BeiDou satellites available. The 24 hour coverage extends westwards to Kuwait. In Houston and Rio only the three MEO satellites are visible.

Fig. 6 shows the visibility for BeiDou satellites from Perth (Australia) and Fig. 7 shows the real-time PPP performance from a monitoring receiver in that location, using only BeiDou MEO, IGSO and GEO satellites. The accuracy of the solution is typically at decimetre level in the horizontal component. The vertical component is a bit more variable, due to a combination of suboptimal geometry and orbit errors.

Fig. 8 shows an example of positioning performance in Oslo using the G4 service. Several MEO and IGSO satellites are visible from Oslo almost all day. In addition, BeiDou GEO satellite C05 is continuously visible from Oslo, albeit at very low elevation (around 12 degrees).

The International Maritime Organization (IMO) Marine Safety Committee (MSC) has during its 94th session 17-19 November 2014: *"recognized the BeiDou Satellite Navigation System (BDS), operated by China, as a part of the World-Wide Radio Navigation Systems (WWRNS)"* [4]. This is the third system recognized after GPS and GLONASS.

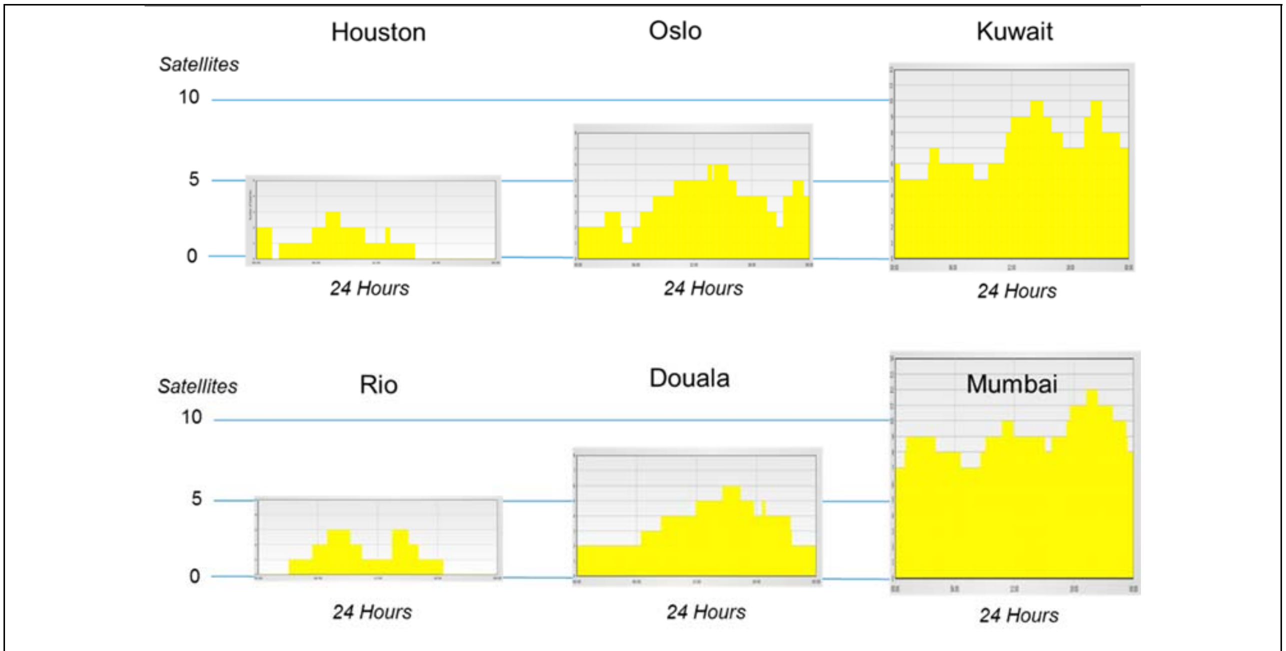

Fig. 5. Examples of the number of BeiDou satellites tracked around the world on 14 October 2015

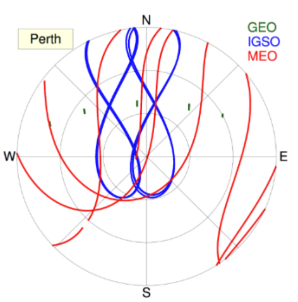

Fig. 6. Sky plot of BeiDou satellites in Perth

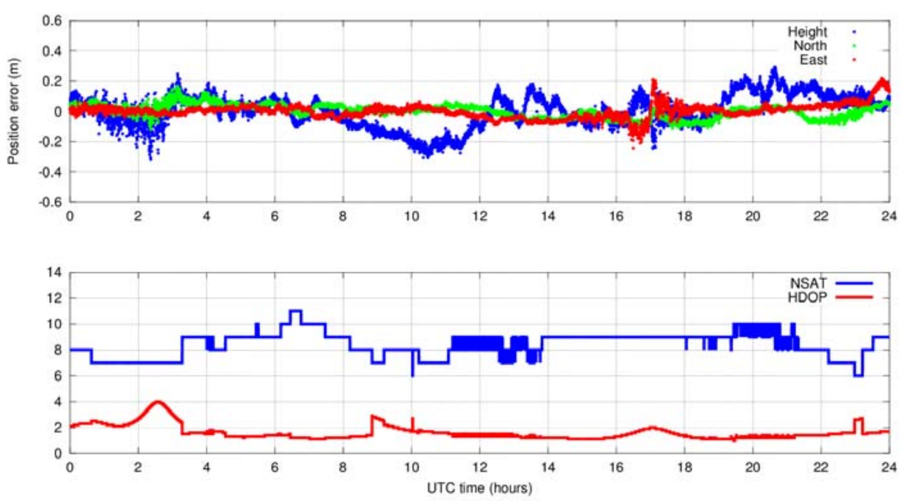

Fig. 7. Example of PPP results using only BeiDou satellites in Perth (Australia), on March 9, 2015.

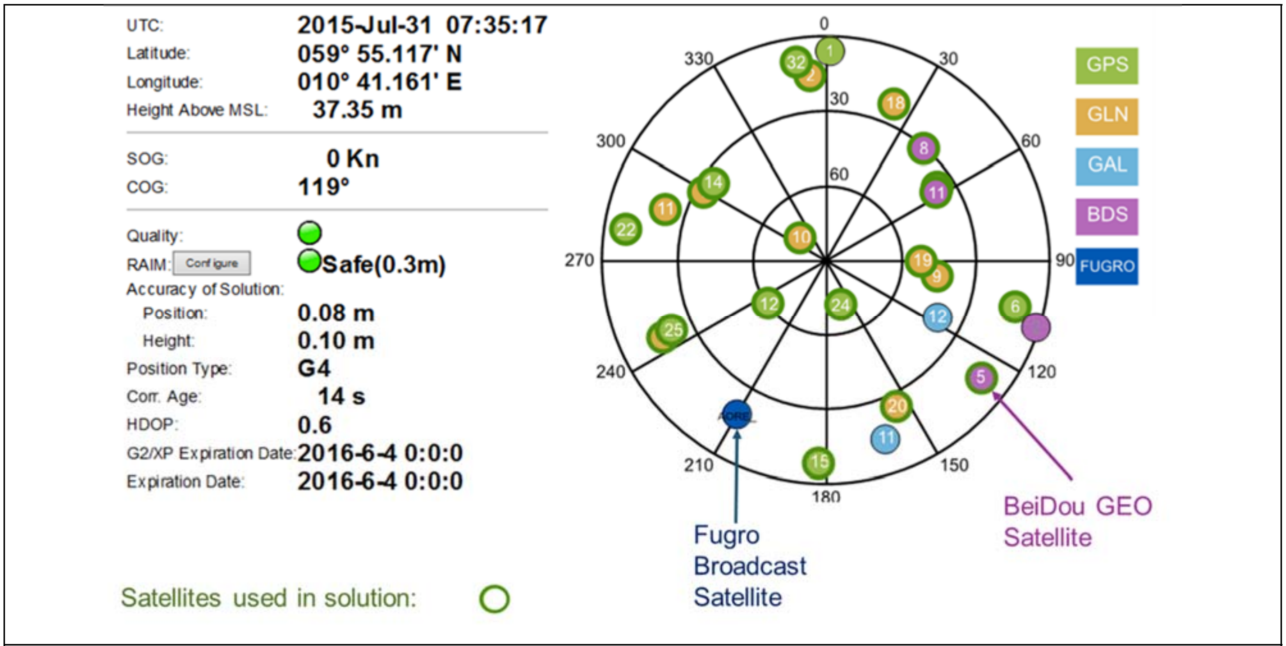

Fig. 7. **Example of satellite coverage using GPS, GLONASS and BeiDou satellites in Oslo (Norway), on 31 July 2015.**

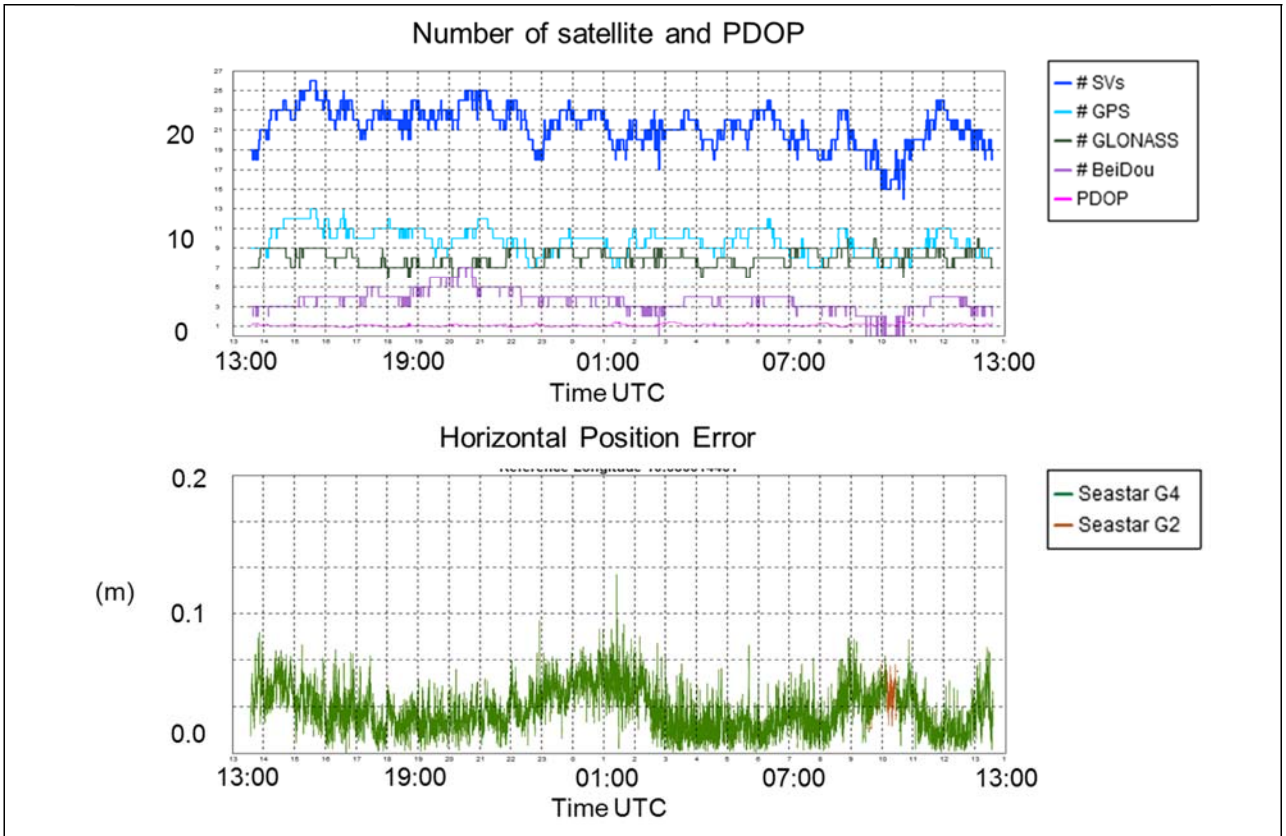

Fig. 8. **Example of PPP results using GPS, GLONASS and BeiDou satellites in Oslo (Norway), on July 30-31 2015.**

Advantages of Multi-GNSS PPP

The addition of new satellite systems to PPP brings improvements in term of accuracy, availability, robustness and convergence time. In terms of accuracy, Fig. 9 shows horizontal and vertical accuracy statistics, for the legacy G2 system and the updated G4 system, in different geographical locations. The higher accuracy is due to the addition of BeiDou satellites, and some recent improvements in the GPS and GLONASS augmentation.

More satellites are particularly useful in difficult tracking conditions when only parts of the sky are visible, or in the presence of interference or scintillation. As an example, Fig. 10 shows horizontal positioning solutions in Seoul (South Korea), which is affected by broadband interference due to nearby RF transmitters. This causes the receiver to lose track of some GNSS satellites part of the day. For this particular case, it can be observed that the G2 solution suffers a reset a needs to re-converge, while the G4 solution is able to deliver a good position most of the time. Thanks to the increased number of satellites with the addition of BeiDou the period of no satellites tracked is reduced to below five minutes and gap bridging can be successfully employed and full re-convergence is avoided.

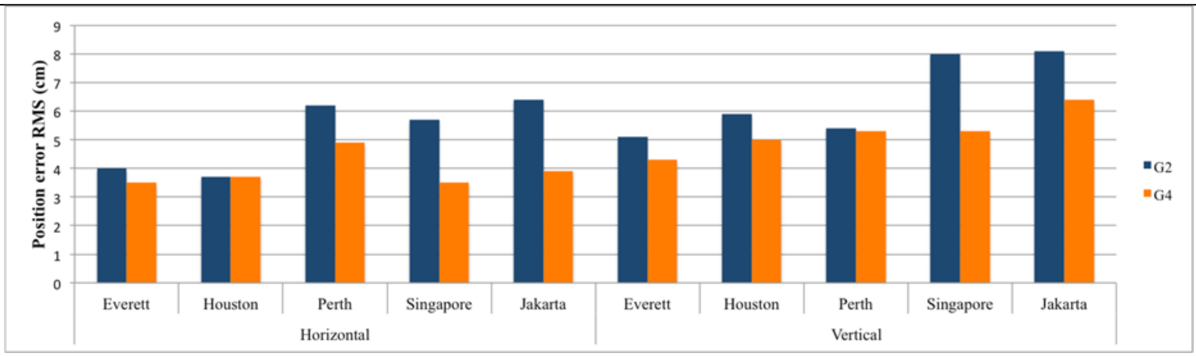

Fig. 9. Accuracy statistics for different locations, using the legacy G2 solution and the new G4 service

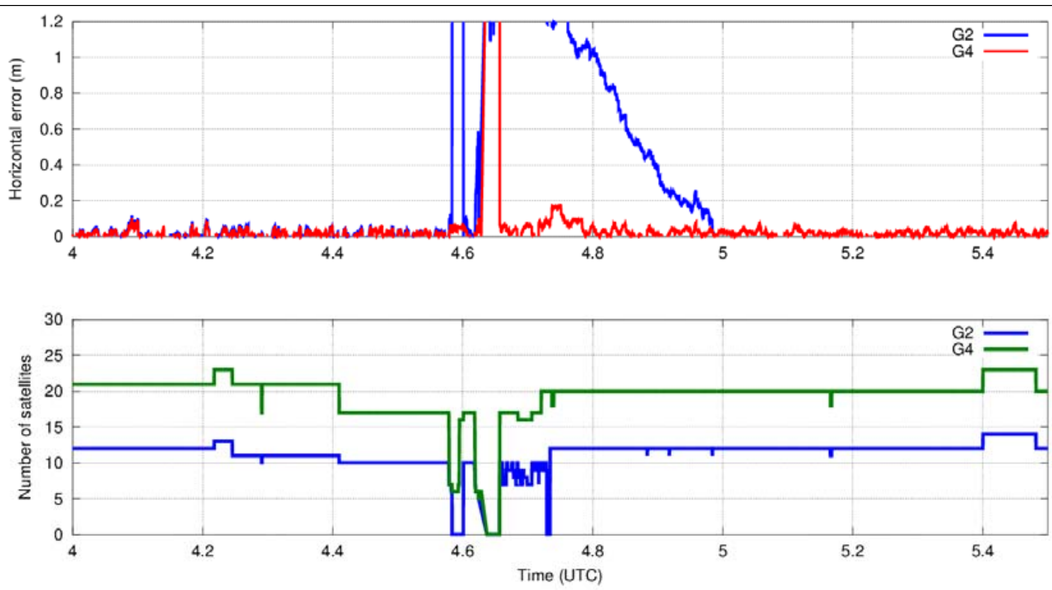

Fig. 10. Horizontal positioning results for Seoul (South Korea) in presence of RF interference.

The more satellites do of course also add to the solution integrity in that more information and redundancy is available to the Receiver Autonomous Integrity Monitoring (RAIM) algorithm checking for and isolating spurious measurements.

Today GPS is the basis of most GNSS setups in DP applications, often together with GLONASS. It is accepted as use of two "independent" setups in DP as long as the augmentation data are independent and provided via independent channels

When BeiDou and Galileo are fully deployed, there will be over 110 satellites in total from all four global GNSS. In this scenario, it can be envisaged that two truly independent solutions can be generated, using two independent corrections stream and for instance GPS+BeiDou and GLONASS+Galileo GNSS combinations, as depicted in Fig. 11. This will two independent positioning solutions in parallel. This kind of setup will have advantages like:

- Each position solution has enough satellites to provide a reliable position with high availability.
- Errors in one GNSS do not affect the other setup.
- Errors in corrections for one GNSS do not affect the other setup.
- A comparison of the independent positions gives an estimate of the position accuracy, even in kinematic scenarios.
- Increased spoofing detection

Conclusion

The Chinese BeiDou GNSS has completed a constellation for regional 24 hour coverage in Asia with 13 operational satellites. The coverage be extended to worldwide by 2020.

Europe is launching more Galileo satellites and will moving towards Early Services in 2016

Fugro introduced the G4 service with BeiDou in Feb. 2015. This service is also Galileo ready.

Additional GNSS provides an opportunity for improved performance in terms of higher accuracy, reliability and availability. It will be possible to generate independent solutions, increasing integrity and the chances to detect spoofing.

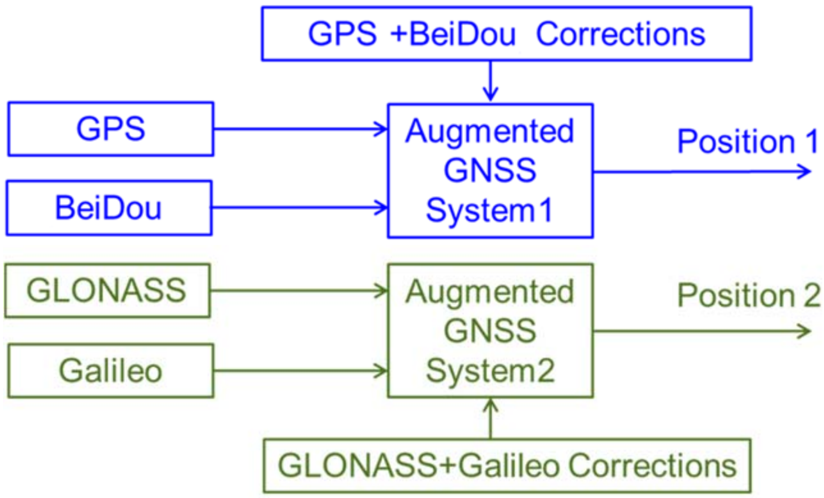

Fig. 11. Possible usage of GNSS systems in the future for the provision of two independent solutions

References

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[2] O. Ørpen, E. Vigen, R.Strandli "Galileo is coming! – How should it be used in DP?" Marine Technology Society Conference - Houston, 15-16 October 2013

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[4] *http://issuu.com/imo-news/docs/24494_imo-news-01-15__6/1* (page 18)

[5] GNSS planning*:* *http://www.trimble.com/gnssplanningonline/#/Settings*