GNSS Modernisation and Its Effect on Surveying

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SUMMARY

GPS and GLONASS modernisation is being undertaken. The current GPS modernisation plan is expected to be completed in about 2025. A completely new proposal for GLONASS modernisation has been released on 27th December 2011. In addition to change from FDMA to CDMA, GLONASS may add three more orbital planes to form a constellation of 30 satellites by 2025. Moreover, the new Galileo and Compass are expected to be in full service in about 2020.

This paper describes the latest GNSS modernisation plans in details and how the modernisation in satellites, signals and constellations affects the positioning accuracy in surveying. Relative positioning technique is usually used in surveying and the baseline length is usually from short to medium (i.e., less than 30 km as defined by the authors). Multipath effect is the main GNSS error source in short to medium baselines. Therefore, impact of GNSS modernisation on multipath mitigation is the focus of this paper.

GNSS modernisation is still on-going, simulation test has to be used to assess the impact of modernised GNSS. Since GLONASS and Compass constellation and signal specifications have not been released officially, impact of the modernised GPS and the new Galileo on multipath mitigation is investigated in this paper. Simulation results show that an about 70% improvement on positioning accuracy in average when compared using combined GPS and Galileo multiple-frequency data with the present GPS reliable single-frequency system (L2C would be available on 24 GPS satellites around 2016). When using three-frequency GPS data, it has shown an about 42% improvement on positioning accuracy in average when compared with the current single-frequency GPS system.

This paper should help surveyors to learn the important aspects of GNSS modernisation in surveying and how GNSS modernisation affects their future surveying practice.

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1. INTRODUCTION

Global Navigation Satellite System (GNSS) carrier phase-based precise positioning is widely used in geodesy, deformation monitoring and various survey applications. Relative positioning technique is usually used in surveying and the baseline length is usually from short to medium (i.e., less than 30km as defined by the authors). Such relative positioning techniques and their associated, and often highly sophisticated, processing algorithms do, however, rely on the fact that they eliminate GNSS biases and errors that are common to receivers over short to medium baselines. As a result it is possible to realise centimetre to millimetre- level positioning accuracies. However, multipath errors are not common to receivers, even over very short baselines. They may substantially degrade the quality of the positioning results if they are not properly taken into account. The maximum error of phase multipath is a quarter of the observing wavelength, for example, it is about five centimetres for GPS L1 carrier. Therefore, multipath mitigation is crucial to achieve centimetre and millimetre-level positioning accuracy. Note that network real-time kinematic (RTK) techniques also suffer from multipath effect because environment-dependent multipath errors affect the receivers of rovers and reference stations differently. Impact of GNSS modernisation on multipath mitigation is the focus of this paper.

The existing literature on multiple-frequency GNSS data processing has tended to concentrate on the use of the more frequencies for improved ambiguity determination. Here this paper addresses a different question. That is: to what extent can multiple frequencies GNSS phase data be used to reduce the impact of multipath in relative positioning? The proposed approach to the problem is based on the averaging (through a rigorous least squares process) of data from combinations of the various frequencies.

2. GNSS MODERNISATION

The current GPS modernisation plan is expected to be completed in about 2025. The IIR(M) series of satellites are an upgraded version of the IIR series, they complete the backbone of today's GPS constellation. The "M" in IIR(M) stands for modernised, it refers to the new civil and military GPS signals added with this generation of spacecraft. The first IIR(M) satellite was launched in September 2005, and the last launch occurred in August 2009. As of 1st February 2012, there were seven healthy IIR(M) satellites in the GPS constellation, with the final one (SVN-49) set to "unusable" status but transmitting signals for test purposes (GPS.gov, 2012). IIR(M) satellites transmit second civilian GPS signal (L2C) for improved performance in commercial applications, and two new flexible power-level military signals providing enhanced military jam-resistance. The IIF series expand on the capabilities of the IIR(M) series with the addition of a third civil signal in a frequency protected for safety-of-life transportation. The "F" in IIF stands for follow-on. Compared to previous generations, GPS IIF satellites have a longer life expectancy (12-year) and a higher accuracy requirement. Each spacecraft uses a mix of rubidium and caesium atomic clocks to keep time within 8 billionths of a second per day. The IIF series will improve the accuracy, signal strength, and quality of GPS. The first IIF satellite launched in May 2010. As of January 2012, there were two operational IIF satellites in the GPS constellation. The current GPS PRNs normally broadcasting L2C are 01, 05, 07, 12, 15, 17, 25, 29, 31, and broadcasting L5 are 01 and 25. However, there are no scheduled launches of GPS Block III with L1C until at least 2015.

The current GLONASS has 24 operational satellites (GLONASS IANC, 2012), 4 of them are GLONASS-M satellites (743 is not operational). On 26th Feb 2011, the first GLONASS-K satellite (GLONASS 701/Cosmos 2471) was launched but the current status is in flight test. The GLONASS-K satellite transmits a CDMA signal in the L3 band that inaugurates a new era of radionavigation signals for both the Russian system and for international GNSS interoperability (Urlichich et al., 2011). As demand for high-precision services through dual- or triple-frequency user equipment increases, GLONASS will come to the forefront. The 2014 GLONASS-K2 satellite will have an FDMA signal in the L1 and L2 bands and CDMA signals in L1, L2, and L3. The overall modernisation is scheduled to be completed in 2021.

The European GNSS, named Galileo, is being developed to provide four carrier frequencies. Galileo signals will be available to users in four categories, they are Open Service (OS), Safety-of-Life (SoL) service, Commercial Service (CS), and Public Regulated Service (PRS). The launch of the first two operational satellites of Galileo took place on 21 October 2011 (EC, 2012). This was just the first of a series of launches due to take off from Europe's Space Port in Kourou, French Guiana. The launch of the Galileo satellites will lead to the provision of initial satellite navigation services in 2014. Full completion of the 30 satellites Galileo system (27 operational + 3 active spares) is expected by 2019 (EC, 2012). Currently, only signals of GIOVE-A (PRN 01/51) and GIOVE-B (PRN 02/52) can be tracked by receivers of various GNSS receiver manufacturers (UNAVCO, 2012).

China is on course to complete a 12-satellite regional version of its Compass (BeiDou-2) GNSS system by 2012, with funding assured through 2020 to complete and operate a full constellation (InsideGNSS, 2009). Compass will consist of 5 geostationary earth orbit (GEO) and 30 MEO satellites transmitting signals on the following carrier frequencies: 1195.14–1219.14MHz, 1256.52–1280.52MHz, 1559.05–1563.15MHz and 1587.69–1591.79MHz. Some of the signals overlay the Galileo PRS band and to a lesser extent the GPS M-code. Compass system currently consists of 6 operational regional satellites (3 GEO+3 IGSO; 1 MEO in test mode).

3. DESCRIPTION OF SIMULATION TEST FOR MULTIPLE-FREQUENCY GNSS

As the GNSS modernised signals aren’t available now, a GNSS data simulator was developed to generate multiple-frequency data for this investigation. The simulator can generate extremely realistic data with biases and errors models such as those due to ionospheric effects, tropospheric effects, orbital errors, measurement noise and multipath. Moreover, GNSS constellations and signal specifications (carrier frequency/wavelength, modulation, chipping rate) must be inputted for realistic simulation. The simulated multipath is validated with real measurements collected in an experiment with known reflector geometry. The real data were processed in order to compare the real multipath errors with those generated by the simulator. The validation results demonstrate the fact that the simulator can produce realistic data for current signals and to justify its use to simulate the GNSS multiple-frequency measurements with multipath used in this investigation of the performance of the future multiple-frequency GNSS in the presence of multipath (Lau and Cross, 2007).

Since GLONASS and Compass constellation and signal specifications have not been released officially, impact of the modernised GPS and the new Galileo on multipath mitigation is investigated in this paper. Moreover, since only the combination of L1, E5a and E5b is open to all users, this paper considers only this combination as Galileo multiple-frequency data. The interoperation of Galileo and GPS will provide the maximum six open signals. Therefore, the possible improvements of precise positioning accuracy in the presence of multipath on Galileo three-frequency data, GPS three-frequency data, and Galileo + GPS multiple-frequency data are investigated in this paper.

4. PROCESSING OF GNSS MULTIPLE-FREQUENCY DATA

In order to carry out the investigation in this paper, a GNSS data processing program was developed to process the different combinations of GNSS data including single-, dual- and three-frequency Galileo or GPS data, and Galileo + GPS multiple-frequency data. The program is based on the double-difference single-epoch least squares solution.
The double-difference technique in the main module of the data processing program eliminates almost all GNSS biases and errors in common to receivers over short to medium baselines. However, multipath errors are not common to receivers, even over very short baselines. In order to investigate the impact of multipath on GNSS multiple-frequency data, five scenarios with different GNSS or combinations of frequencies are tested:

- Scenario 1: the current reliable single-frequency GPS data (the current L2 signal is weak and noisy; L2C would be available on 24 GPS satellites around 2016),
- Scenario 2: the modernised dual-frequency GPS data,
- Scenario 3: the future three-frequency GPS data,
- Scenario 4: the future OS three-frequency Galileo data, and
- Scenario 5: the future OS Galileo + GPS multiple-frequency data.

Simulation of GNSS testing data is based on the experimental setup as described in [Lau and Cross, 2007]. The geometry of Galileo and GPS satellites and the reflector relative to the roving receiver is plotted in the sky plot shown in Fig. 1. Variable damping factor is used in the scenarios in order to account for the GNSS signal parameters such as the carrier frequency and chipping rate. Moreover, normal distributed random measurement noise with standard deviation of one millimetre is generated for each phase measurement. The processing results of these scenarios will be given in next section.

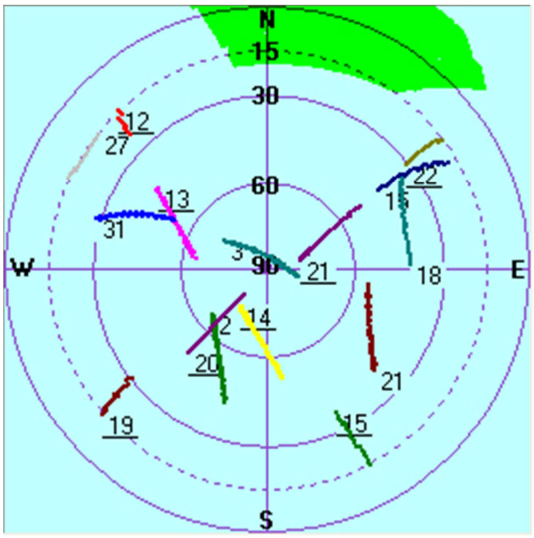
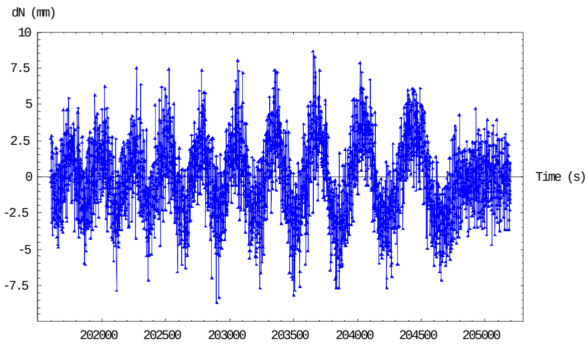
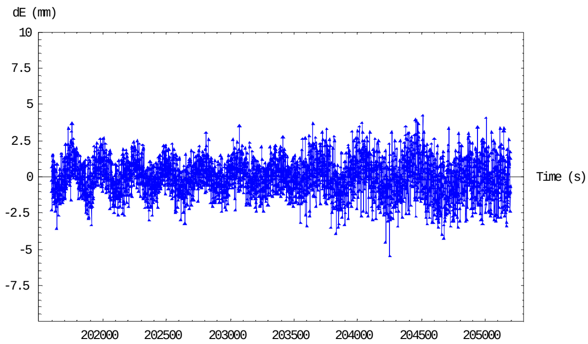


Fig.1. Sky plot of Galileo (underlined) and GPS satellites; the green area represents the reflector .

5. RESULT OF MULTIPATH FREQUENCIES GNSS DATA PROCESSING AND ANALYSIS

Positioning errors from single epoch solutions in nothing, easting, and height for scenarios 1 to 5 are shown in Figs. 2 to 6 respectively. Statistical results including the mean and standard deviation (SD) of the positioning errors in northing, easting, height, and 3D position are tabulated in Table 1. Since the positioning errors are mainly due to multipath and slightly due to measurement noise and multipath errors and measurement noise may result in a zero mean, the maximum and minimum positioning errors in northing, easting, height, and 3D position error of the scenarios are given in Table 2.





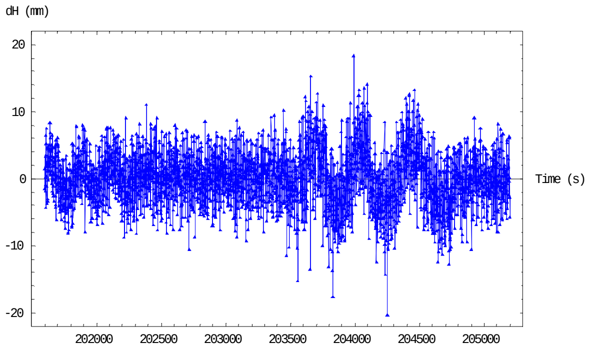


Fig.2. Positioning error in northing (top left), easting (top right), and vertical (bottom left) of single-epoch solution using GPS single-frequency data.

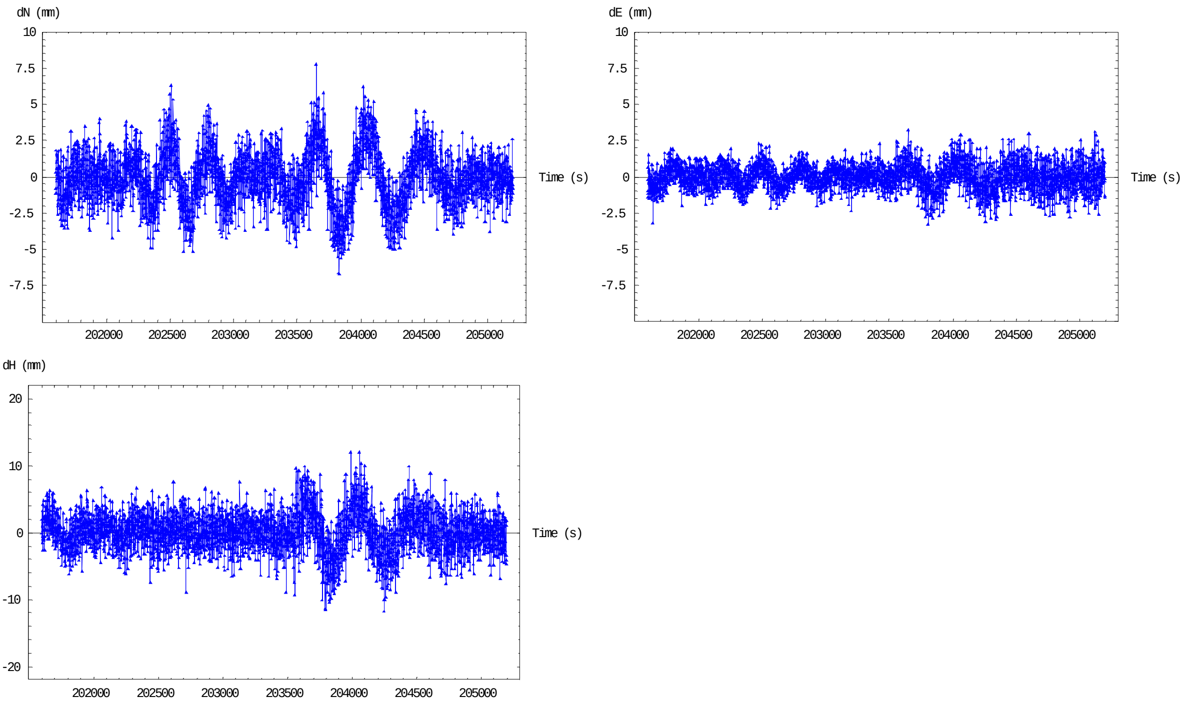
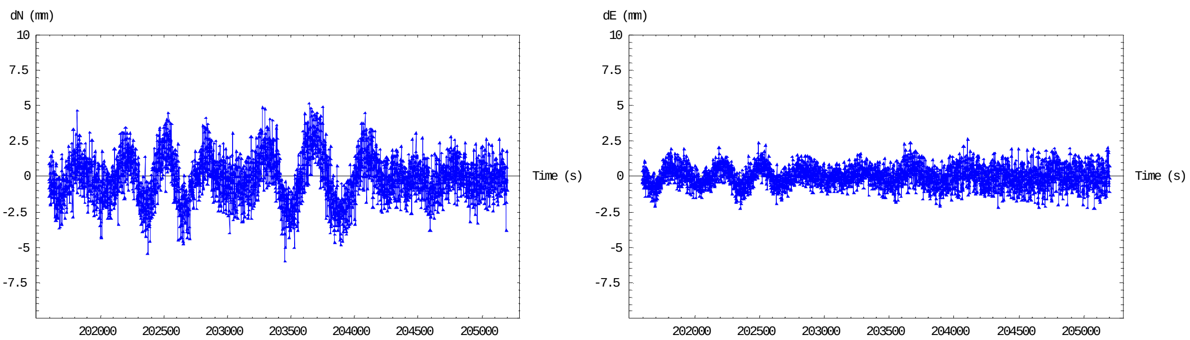


Fig.3. Positioning error in northing (top left), easting (top right), and vertical (bottom left) of single-epoch solution using GPS dual-frequency data.



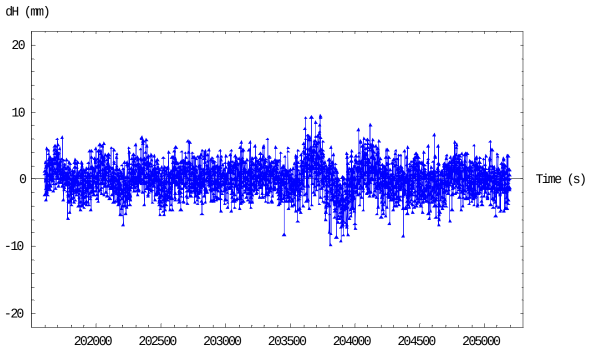


Fig.4. Positioning error in northing (top left), easting (top right), and vertical (bottom left) of single-epoch solution using GPS three-frequency data.

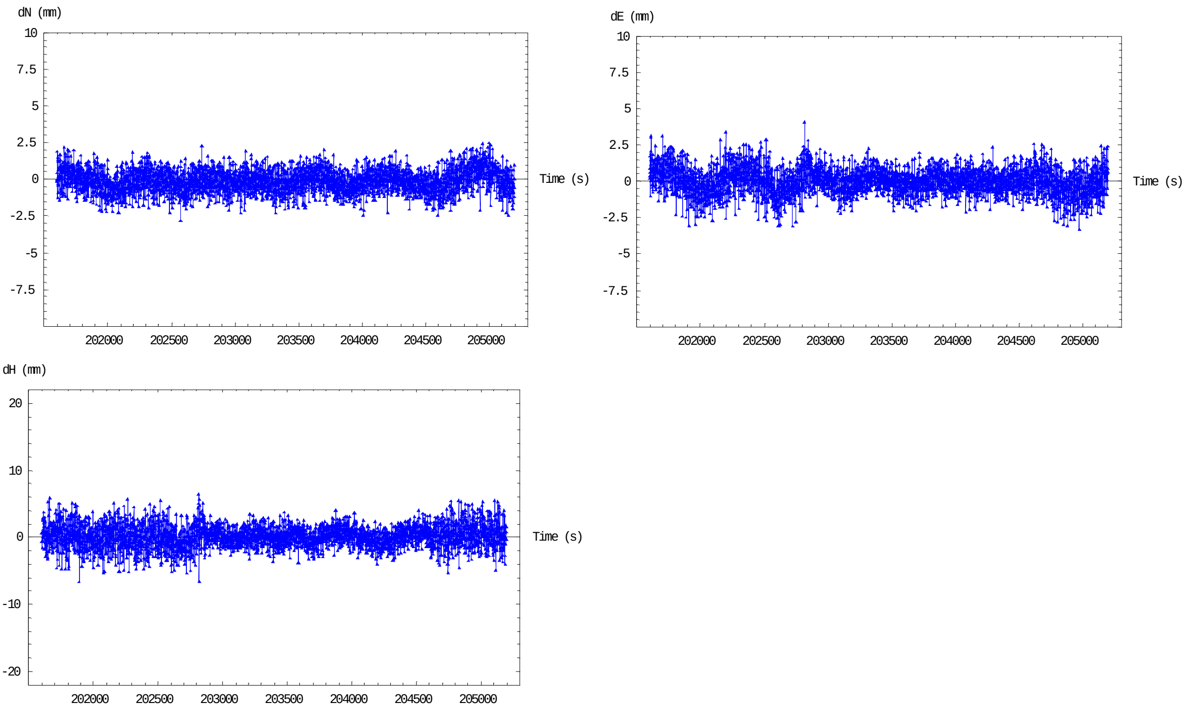
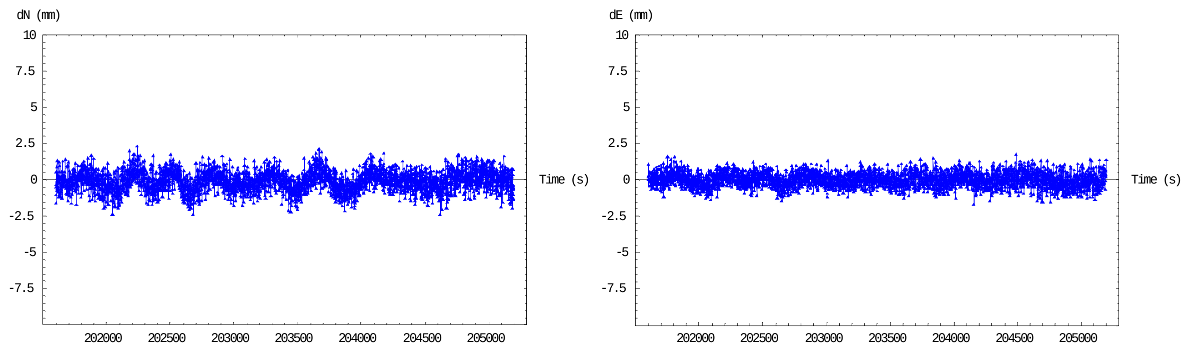


Fig.5. Positioning error in northing (top left), easting (top right), and vertical (bottom left) of single-epoch solution using Galileo three-frequency data.



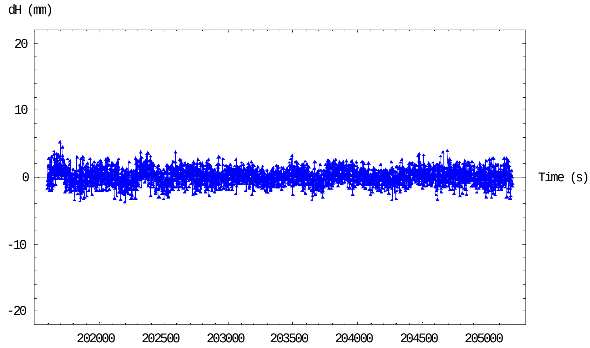


Fig.6. Positioning error in northing (top), easting (middle), and vertical (bottom) of single-epoch solution using Galileo + GPS three-frequency data.

The obvious sinusoidal pattern in Fig. 2 shows the serious multipath induced positioning error when using GPS single-frequency data in single-epoch solution. When modernised GPS dual-frequency data are used, a slight reduction in multipath effect can be found in Fig. 3. From Figs. 3 and 4, we can see that the multipath effect on single-epoch solution using GPS three-frequency data becomes slightly less significant when compared with using GPS dual-frequency data. When moving from GPS three-frequency data (Fig. 4) to Galileo + GPS multiple-frequency data (Fig. 6), a substantial reduction in multipath effect on single-epoch solution can be seen.

The statistical results in Tables 1 and 2 show that the use of modernised GPS dual-frequency data has about 28% improvement on positioning accuracy when compared with GPS single-frequency data. The use of GPS three-frequency data has about 19% improvement on positioning accuracy when compared with modernised GPS dual-frequency data. It is due to the fact that multipath errors are frequency dependent so the effects on different frequencies are different as shown in Fig. 7, therefore, the additional frequency leads to better averaging of multipath effects within the least squares process.

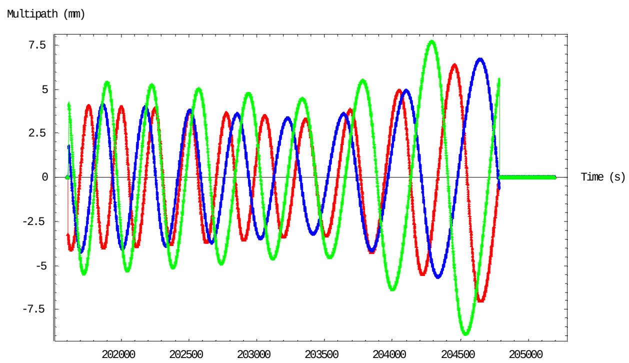


Fig.7. Simulated GPS three-frequency (red: L1, blue: L2, green: L5) multipath error in PRN02.

From the statistical results in Tables 1 and 2, positioning accuracy of using Galileo three-frequency data shows about 28% better than that of using GPS three-frequency data. It is because the geometrical effect of this Galileo data set that multipath contaminates the three-frequency data less in-phase when compared with the GPS three-frequency data set. It can be found in Figs. 7 to 9. Only data from PRN02 in GPS three-frequency data are contaminated by multipath, the simulated multipath effect on GPS PRN02 is shown in Fig. 7, however, data from two Galileo satellites are affected by multipath, the simulated multipath on Galileo SV14 and SV20 are shown in Figs. 8 and 9 respectively. Least square process averages the multipath effect on Galileo data better than on GPS data in this simulated data set even though there are two Galileo satellites' data are contaminated by multipath.

Galileo + GPS multiple-frequency data shows about 49% improvement, which can be determined from Tables 1 and 2, on positioning accuracy when compared with GPS three-frequency data. Again, it is due to better averaging of multipath in least squares process with more redundant data from dual constellations. From the current reliable GPS single frequency to the coming maximum number of frequencies in open service - Galileo + GPS multiple-frequency data, the statistical results in Tables 1 and 2 show about 70% improvement on positioning accuracy.

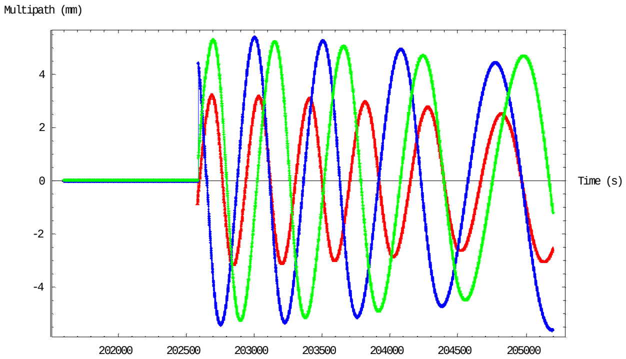


Fig.8. Simulated Galileo three-frequency (red: L1, blue: E5a, green: E5b) multipath error in SV14.

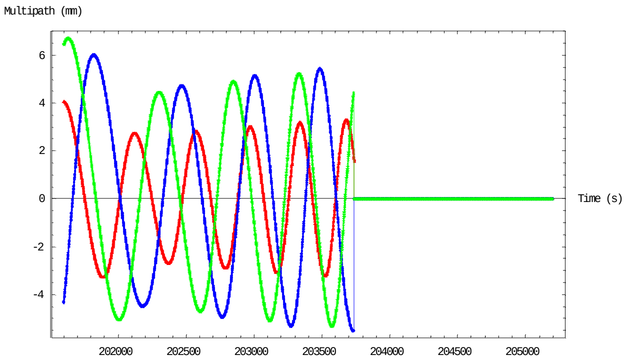


Fig.9. Simulated Galileo three-frequency (red: L1, blue: E5a, green: E5b) multipath error in SV20.

Table 1. Statistical results of positioning errors in millimetres using different GNSS multiple-frequency simulated data.

	Mean			SD			3D positioning error	
System	dN	dE	dH	dN	dE	dH	Mean	SD
GPS Single	-0.1909	-0.0594	-0.0084	2.6216	1.2496	4.0605	4.3361	2.4809
GPS Dual	-0.1484	-0.0264	0.0639	1.8903	0.8996	2.9693	3.1157	1.8750
GPS Three	-0.1725	-0.0239	-0.0147	1.5853	0.7200	2.3217	2.5315	1.4290
Galileo Three	-0.1315	-0.0175	0.0885	0.7817	0.9221	1.6922	1.8229	1.0131
Galileo+GPS	-0.1265	-0.0157	0.0552	0.6876	0.4903	1.1452	1.2795	0.6376

Table 2. Maximum and minimum positioning errors in millimetres using different GNSS multiple-frequency simulated data.

	Maximum				Minimum			
System	dN	dE	dH	3D pos error	dN	dE	dH	3D pos error
GPS Single	8.6548	4.2261	18.2542	21.7894	-8.7112	-5.5100	-20.4428	0.2692
GPS Daul	7.7430	3.2057	12.0350	13.1162	-6.6859	-3.2968	-11.8235	0.0581
GPS Three	5.1467	2.6200	9.4018	10.5940	-6.0098	-2.2663	-9.7956	0.0683
Galileo Three	2.4749	4.0802	6.4467	7.6779	-2.8458	-3.3332	-6.7200	0.0587
Galileo+GPS	2.2871	1.7242	5.2372	5.2440	-2.3945	-1.6762	-3.7171	0.0443

6. CONCLUSIONS

The impact on positioning accuracy in the presence of multipath using multiple-frequency data from the coming modernised GPS and Galileo in open service is investigated. GNSS data simulator and processor were developed to generate and process GNSS multiple-frequency data respectively for this study. Galileo and modernised GPS multiple-frequency data are simulated in order to investigate the impact of using modernised GPS, Galileo and the dual constellations on positioning accuracy in the presence of multipath. Simulation results show substantial improvement on positioning accuracy when more frequencies and satellites are available. It shows about 70% improvement when compared using Galileo + GPS multiple-frequency data with the present GPS reliable single-frequency system (L2C would be available on 24 GPS satellites around 2016). Although the exact future positioning accuracy of Galileo and modified GPS can be verified when they are fully operational and the positioning accuracy depends on GNSS errors and satellite geometry, the performance of the coming GNSS would be expected to have the similar positioning accuracy because the simulation described in this paper is very realistic. This paper shows the potential positive impact of GNSS modernisation in the future surveying practice.

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BIOGRAPHICAL NOTES

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