Role of Multi-Constellation GNSS in the Mitigation of the Observation Errors and the Enhancement of the Positioning Accuracy

Kandil, I.,[1*] Awad, A.[2] and El-Mewafi, M.[3]
Public Works Engineering Department, Faculty of Engineering, Mansoura University, Mansoura 35516, Egypt, E-mail: islamaboelnaga@hotmail.com,[1*] ahmedawad@mans.edu.eg,[2] mmewafi1@mans.edu.eg[3]
Corresponding Author

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Abstract

Using Precise point positioning (PPP) technique can help to reach decimeters accuracy for positioning by using one receiver only. Since it set to track Global Navigation Satellite System (GNSS). Recently BeiDou and Galileo systems have been devolved periodically and increasing the number of working satellites. Addition to those all-global Navigation systems is able to receive triple frequency signals. The effect of using Multi constellation of GNSS and combination of different systems with each other's need to be investigated. In this paper, four Multi GNSS EXPERIMENT (MGEX) stations with 24 hours observation files and 30 second interval time during a 1 week of averaged data of January 2020 (2134 GPS week) are used to investigate the accuracy of using combined solution of GNSS with 12 cases of study. Data were processed by PPPH program. To investigate the effect of using the different GNSS combinations while using the PPP method, contrast experiments have been tested by mixing dual frequency ionospheric-free PPP models in static mode with G only, GLO only, G + GLO, G+ B, GLO+B, G+GAL, GLO+GAL, GLO+B+GAL, GNSS, G +GAL+B, G+GLO+B and G+GLO+GAL combination cases, where G refers to GPS, GLO refers to GLONASS, GAL refers to Galileo and B refers to BeiDou. The results show that the combined GPS and Galileo observation in PPP solution improves the convergence time and gives the shortest convergence time of the 12 study cases with average value 53 minute and with minimum value 35 minute. By comparing the root mean square error (RMS) values, the combination of G+GL+B had the minimum RMS error in North and East direction with minimum value 1.2 cm, maximum value 1.8 cm and average value1.45 cm. And the combination of GLO+GAL+B had the minimum RMS errors in up directions with average value 2.775 cm and minimum 2.775 cm and maximum 4.5 cm. In conclusion, the results indicate that the combination of different GNSS can give more accurate solution of the PPP. The combined PPP has shown an improvement in the convergence time in the case of using combined of G and GAL observation, while the positioning accuracy after convergence has no shown significant improvement. The result of G+GAL+B give the minimum RMS error in North and East direction and the combination of GLO+GAL+B give the minimum RMS errors in up directions.

Keywords: Convergence time, GNSS, Multi constellation, Multi GNSS, PPPH, Precise Point Positioning (PPP).

1. Introduction

Previously, the users of the Global Navigation satellite system (GNSS) usually were using the American system which called GPS as the GPS is the oldest and the most famous satellite system in the world. After that, some of other users used the Russian System which called GLONASS. Nowadays, after the appearance of the Chinese system which called BeiDou (BDS or B) and the European system which called Galileo, a new technique appeared for positioning depending on the combination and constellation of the four global navigation systems. Recently, China lunched BDS-3 and enter to the service on 27/12/2018 (http://en. beidou.gov.cn/). In last years, BeiDou became including satellites for geostationary earth orbit (GEO), satellites of inclined geosynchronous orbit (IGSO), and satellites of medium earth orbit (MEO). In November, 2019 China lunched five satellites of GEO, seven satellites of IGSO, three satellites of MEO all of them are included in BeiDou 2 and nineteen satellites of BeiDou 3 in normal operation [1].

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Precise point positioning (PPP) is a positioning technique depends on one receiver, provides decimeter level positioning accuracy and mitigates the errors of the observations [2]. Nowadays most of the users who need high accuracy level and low cost usually used this method due to its high efficiency in GNSS data processing and avoidance of using nearby reference stations to process [3].

By combining the observation of BDS, Galileo, GLONASS and GPS, the convergence time of PPP can be affected [4]. The aim of the most users who need high accuracy level and low cost is reducing the convergence time, initialization time and improving reliability. By using the quad-constellation with BDS and Galileo specially after entering the new satellites in the operation, their using and combining them to each other's will be tested. Now, the satellites of the GPS and GLONASS can receive dual frequency signals, and also no, thirteen of the satellites of GPS system and two of the satellites of GLONASS system can receive triple frequency signals. Now, different satellite systems like GPS, GLONASS, BeiDou and Galileo can receive multi frequency signals like dual and triple frequency signals, for example, for BDS system B 1, B 2, B 3 and for Galileo system E 1, E 5a, E 5b, E 5, E 6 [5]. as the observations of each frequency is not dependent on each other and using raw observations is more effective for multi frequency PPP [6].

As the combination between the Four major Navigation system in PPP by using raw observations of all the multi frequencies did not have enough study, so, to reach best use of multi frequency GNSS measurements, the potentials of multi frequency and using different GNSS data processing should be widely investigated [7]. The development of the GNSS systems have two main advantages for the geodetic work. The first one is decreasing the dependent on the result of GPS signals by having results from the other GNSS systems. The second one is by combination of the raw observation files between different GNSS systems will improve the geometry of the observed satellites that's because increasing the numbers of visible satellites [8]. For this reason, adding the other GNSS satellites systems and make constellation of the different systems will enhance the accuracy specially in urban area as the huge numbers of tracked satellites will give a chance to neglect the weak signals or the weak accuracy satellite [9]. To Avoid the blocking satellite, the observations of the GPS and other GNSS systems like (GLONASS), the (BEIDOU) and (GALILEO) can be combined [10].

The constellation of BEIDOU, Galileo, or GLONASS systems to GPS will increase the number of the visible satellites on the sky and can improve the positioning dilution of precision (PDOP) values [11]**.** The International GNSS Service (IGS) establish multi GNSS experiment (MGEX) which track all available GNSS data and IGS analyzes all the data [7].

IGS analysis centers (ACs) recently collect and analyze the precise orbits and clock and multi frequency differential code bias (DCB) products for different GNSS systems and these products support the high accuracy of the PPP method. The data of four MGEX stations were collected during a 1 week in January 2020 in 2134 GPS week and all of the stations are a class A stations and belongs to IGS. Then the RINEX 3 file for each station and the related products were downloaded and PPP performance based on multi-frequency raw observations and dual-frequency measurements was analyzed. The methodology used in the research is descripted in the (Methodology) section. The process strategy and the experiment Network is descripted in the (The process strategy and the experiment Network) section. "Results and Analysis" section show the results of the research and the analysis of the data, and the conclusions of the research shown in "Conclusions" section.

2. Methodology

Every system of GNSS use different reference frame, different signal structure, and time scale. This difference must be taken in the consideration when using the PPP processing method on Multi GNSS. As used in this research, the precise products for the orbits and the clock were generated from IGS. There is no need to transform the reference frame or signal structure or time scale and also there is no need to use any transformations from any system. By using the products downloaded from the IGS organization that mitigate the errors but we still need to solve the satellites and receivers' hardware biases [12].

$$P_{i,r}^{s.n} = \rho_r^{s.n} + cdt_r^{s} - cdT^{s.n} + Trop_r^{s.n} + Ion_r^{s.n} + b_{i,r}^{s} - b_i^{s.n} + \mathcal{E}\,(P_{i,r}^{s.n}) \qquad \text{Equation 1}$$

$$\phi_{i,r}^{s.n} = \rho_r^{s.n} + cdt_r^{s} - cdT^{s.n} + Trop_r^{s.n} - Ion_r^{s.n} + \lambda_i^{s} N_i^{s.n} + B_{i,r}^{s} - B_i^{s.n} + \mathcal{E}\,(L_{i,r}^{s.n}) \qquad \text{Equation 2}$$

Where:

r is the receiver

i is the frequency of the navigation signal

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s is GNSS system as G, GL, GAL, and B for the GNSS systems GPS, GLONASS, Galileo and Beidou
n is satellite number
$P_{i,r}^{s.n}$ is measured pesdourange (m)
$\rho_r^{s.n}$ is geometric distance between the antenna of satellite s and the receiver r,
c is speed of light in vacuum(m/sec);
cdt_r^s is receiver clock error (sec)
$cdT^{s.n}$ is satellite clock error (sec)
$Trop_r^{s.n}$ is tropospheric delay error(m)
$Ion_r^{s.n}$ is ionospheric delay error(m)
$B_{i,r}^s$ is receiver hardware code biases on frequency(m)
$B_i^{s.n}$ is satellite hardware phase biases on frequency(m)
$\phi_{i,r}^{s.n}$ is measured carrier phase (m)
$N_i^{s.n}$ is integer cycle (cycles)
λ_i^s is length of the wave of the frequency(m)
$\mathcal{E}$ is receiver carrier phase noise(m).

Usually, when using PPP technique, the users used the precise products downloaded from the IGS to mitigate the errors. These products which downloaded from IGS are obtained by using the ionospheric free (*IF*) linear combination of code pseudo range observations. The related clock offsets include the hardware code biases [13]. So, the hardware code biases error of the satellite can be merged with the clock error of the satellite and disappear when the precise products used in *IF* linear combination. Likewise, the code biases error of the receiver hardware could be merged with the clock error of the receiver as it is not estimable for undifferenced observation equations due to its high correlation with the clock of the receiver. By the way, it is impossible to make correction of the hardware phase biases for the satellite and the receiver by using the products of the IGS. That is why when the high accuracy positioning is not the main goal it usually ignored or merged with the parameter of ambiguity. For the second case, the parameter of ambiguity is already merged with the hardware biases and it is not an integer any more [14]. Due to what mention before, *IF* combinations of dual frequency ($I = 1, 2$) code pseudo range and phase observations could be illustrated from the previous equations 1 and 2 as the following equations:

$$P_{if,r}^{s.n} = \rho_r^{s.n} + cdt_r^s - cdT^{s.n} + Trop_r^{s.n} + \mathcal{E}\,(P_{i,r}^{s.n})$$

Equation 3

$$\phi_{if,r}^{s.n} = \rho_r^{s.n} + cdt_r^s - cdT^{s.n} + Trop_r^{s.n} - Ion_r^{s.n} + \lambda_i^s + N_i^{s.n} + \mathcal{E}\,(L_{i,r}^{s.n})$$

Equation 4

Where:

$c\,dt_r^s = cdt_r^s + B_{if,r}^s$

$cdT^{s.n} = cdT^{s.n} + B_{if}^{s.n}$

$N_{if}^{s.n} = N_{if}^{s.n} + (B_{if,r}^s -- b_{i,r}^s) - (B_{if}^s -- b_i^s)$

GLONASS system uses different signals called Frequency Division Multiple Access (F.D.M.A) signals, the main idea is every satellite of GLONASS system have its own hardware bias and different channel of frequency [15] So, the hardware biases of the GLONASS can be defined as the summation of the average term and a frequency dependent term. The frequency dependent terms can be defined to as inter frequency biases (IFBs). Recently, as the hardware code biases are neglected by the precise products and the satellite and the receiver phase biases can be evaluated with the parameters of the ambiguity, so the IFBs of receiver hardware code biases only must be taken into the calculations and it may be evaluated by adding it as a parameter in the PPP process and that will increase the unknown parameters in the equation of process. After that it is too much unknown parameters in the structure equation, so it is better not adding the code IFBs in the equation because it is very small comparing to the carrier phase observations is designated for the code pseudo-range observations. So, it can be neglected and the effect of it can be appear in the residuals of the code pseudo - range [12].

In equations no (3) and (4), the parameter of the receiver clock offset is submitted for every GNSS individually. instead of calculating different receiver clock offsets it is an easy way to explain the difference in system time parameters for Galileo, BeiDou and GLONASS which related to the clock offset of the GPS system. Assuming that the modified clock offsets contain hardware biases, the difference in the parameter of the time system is the summation of the real system time difference between the different GNSS systems and GPS and the hardware biases. Assuming that the modified clock offsets also contain the hardware biases, the difference in the parameter of the system time is the summation of the real difference in the time between every individual GNSS system and GPS and the hardware biases [12]. When using the precise products and modifying the difference of the parameters of each system according to the receiver clock offset of the GPS system, the equation of IF observation for each GNSS system can be descripted as:

$$P_{if,r}^{G.n} = \rho_r^{G.n} + cdt_r^G + Trop_r^{G.n} + \mathcal{E}\,(P_{if,r}^{G.n})$$

Equation 5

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$$\phi_{if,r}^{G.n} = \rho_r^{G.n} + cdt_r^{G} + Trop_r^{G.n} + \lambda_{if}^{s} N_{if}^{G.n} + \mathcal{E}(L_{if,r}^{G.n})$$

Equation 6

$$P_{if,r}^{GL.n} = \rho_r^{GL.n} + cdt_r^{GL} + Trop_r^{GL.n} + \mathcal{E}(P_{if,r}^{GL.n})$$

Equation 7

$$\phi_{if,r}^{GL.n} = \rho_r^{GL.n} + cdt_r^{GL} + Trop_r^{GL.n} + \lambda_{if}^{s} N_{if}^{GL.n} + \mathcal{E}(L_{if,r}^{GL.n})$$

Equation 8

$$P_{if,r}^{GAL.n} = \rho_r^{GAL.n} + cdt_r^{GAL} + Trop_r^{GAL.n} + \mathcal{E}(P_{if,r}^{GAL.n})$$

Equation 9

$$\phi_{if,r}^{GAL.n} = \rho_r^{GAL.n} + cdt_r^{GAL} + Trop_r^{GAL.n} + \lambda_{if}^{s} N_{if}^{GAL.n} + \mathcal{E}(L_{if,r}^{GAL.n})$$

Equation 10

$$P_{if,r}^{B.n} = \rho_r^{B.n} + cdt_r^{B} + Trop_r^{B.n} + \mathcal{E}(P_{if,r}^{B.n})$$

Equation 11

$$\phi_{if,r}^{B.n} = \rho_r^{B.n} + cdt_r^{B} + Trop_r^{B.n} + \lambda_{if}^{s} N_{if}^{B.n} + \mathcal{E}(L_{if,r}^{B.n})$$

Equation 12

Where:

cdt_r^{GL} is time difference parameter for GLONASS with accordance to GPS time

cdt_r^{GAL} is time difference parameter for Galileo with accordance to GPS time

cdt_r^{B} is time difference parameter for BeiDou with accordance to GPS time.

Equations 5 to 12 contain the structure equation of constellation multi GNSS PPP which used in the most PPP software for processing [13].

3. Experimental Network and the Strategy Process

For this research four MGEX stations located in Europe are selected to make a comparative study of the network processing by using 12 different cases of constellation and combination between different GNSS systems as shown in Table 1. The following map show the location of the selected MGEX stations (Figure 1). The main aim of the research is to investigate the possible benefit of using combined navigation satellite solution and the effect of using this combination on the convergence time. The used data in the research are the raw data of RINEX file for four MGEX stations and the version of the RINEX file is 3.04 downloaded from IGS and all stations are equipped with receiver set to track the four navigation systems. The observation period is during the GPS week 2134. A PPP processing software called PPPH are used in this research. PPPH allows users to upload some necessary files such as the observation file, sp3 file for the observation, previous and next day, the clock file and antenna file for the used receiver and have a variety of outputs such as the convergence time, the positioning errors and root means square errors and give a file included calculated coordinates for each epoch and gives analysis diagrams for 3D positioning errors, North East UP positioning error, receiver clock estimation, tropospheric zenith total delay, the number of satellites and dilution of precisions [13]. The convergence time can be illustrated as it is the necessary time needed to reach a very low positioning error in the three directions (east, north, up) or 3D positioning and the error value must be less than the values defined before that for the recent epoch and the next twenty epochs, and it’s taken one decimeter [16]. Table 2 shows the used data for process the observation files for MGEX RINEX file and filters for mitigate errors.

The used receivers in the experiment are able to track and receive multi GNSS observation data. The interval sample of the observations is 30 second the data collected during 1 week Period of January 2020. The precise orbits of the satellites and the clock products from “IGS” downloaded from the official website are used. The cut off angle used in the all cases of study was set to eight degrees and the antenna calibration data are obtained from the epn_14_2134.atx file. The precise coordinates of the stations used on the test was generated from the IGS weekly SINEX file and used to investigate the positioning errors, root means square errors and convergence time. The indications “G”, “B”, “GLO” and “GAL” are used to indicate to the GNSS systems GPS, Beidou, GLONASS and Galileo. The convergence time can be illustrated as reaching a very low positioning error in the three directions (east, north, up) or 3D positioning less than the values defined before that for the recent epoch and the next twenty epochs and it’s taken one decimeter [16].

The comparison results of positioning accuracy and convergence time in E, N, U, and 3D direction for the different cases are illustrated in Tables 3, 4, 5, 6 for each station individually for 1-week averaged positioning errors. Table 7 shows the average Positioning error and RMS and convergence time for all station for each solution for the four points for all cases and the Figures 1, 2, 3, 4 show the 3D positioning errors for each station in the 12 cases of study during first 5 hours of observations since it is noted that the errors after 2 hours of observations was steady and stable.

Table 1: Different Study Cases

Study Cases	
G	GLO + B
GLO	G + GLO+ B
G+ GLO	G + GLO + GAL
G+ GAL	G + GAL + B
G + B	GLO + GAL + B
GLO + GAL	GNSS

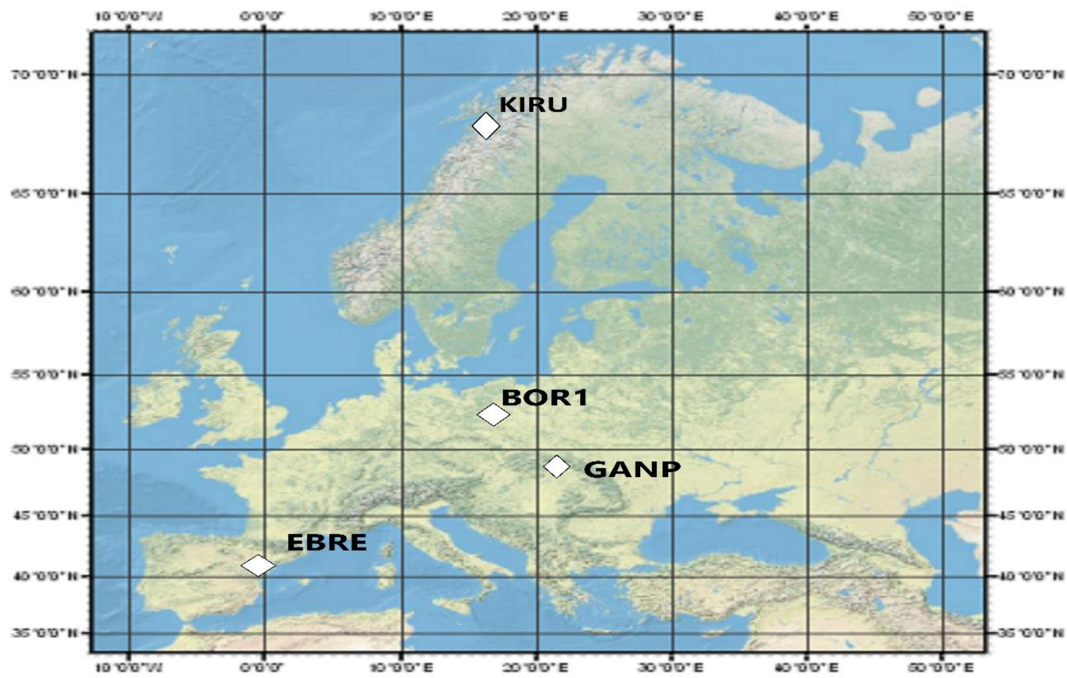

Figure 1: Geographical distribution of MGEX stations used in this study

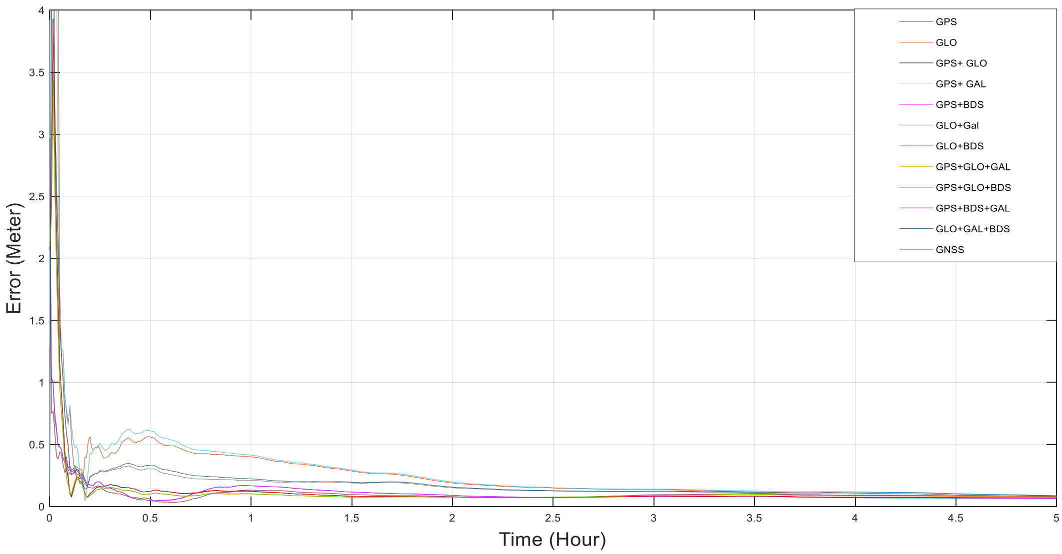

Figure 2: 3D positioning error at EBRE station

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Table 2: Processing strategies

The Processing mode	Static
The orbit and clock of the Satellite	The final Products from IGS
IGS stations	All Belongs to IGS Network
Classified Class	A
Used RINEX Version	3.04
The antenna file of the Satellite and receiver	I G S ANTEX. file
Organization	BKG
The observables Model	Undifferenced, ionosphere-free linear combination of dual frequency code and phase observations
The weighting scheme	Elevation dependent weighting [sin (el)] and the correlations ignored
The mask elevation angle	8 °
The observables Standard deviations	Code pseudo range= default 3 m at zenith Carrier phase=default 0.003 m at zenith
The dry model of Tropospheric delay	Saastamoinen (GPT2)
The wet model of Tropospheric delay	Calculated
The used mapping function	GMF
Gradients	Not applied
The effects of relativistic	Taking into consideration and applied [17]
The effect of Phase wind up	Taking into consideration and applied [18]
The site displacement	The ocean loading and the solid Earth tides are applied [19]
The filter used for adjustment	Extended Kalman filter
Outputs	The positioning, receiver clock bias, tropospheric wet delay, ambiguity parameters and convergence time

Table 3: Positioning error and RMS and convergence time for BOR1 station for each solution

Station	**Case**	**Positioning Errors(cm)**			**RMS (cm)**			**Convergence time (Epoch)**
BOR1		East	North	Up	East	North	Up	
	G	0.0	-1.0	-4.5	1.6	2.7	5.2	44
	GL	2.1	-0.2	-1.6	1.9	1.3	3.7	218
	G+GL	0.7	-0.3	-3.6	1.1	1.8	5.5	65
	G+B	-0.1	-1.0	-3.9	1.6	2.7	4.7	43
	GL + B	1.4	0.5	-2.1	1.3	1.4	3.2	209
	G+GAL	0.0	-0.9	-4.0	1.6	1.4	4.8	35
	GL+GAL	1.3	0.1	-2.5	2	0.6	3.6	65
	GL+B+GAL	1.0	0.6	-2.2	1.8	0.8	3.3	65
	G+GAL+ B	-0.1	-0.9	-3.6	1.6	1.4	4.5	35
	G+GL+ B	0.5	-0.4	-3.3	0.8	1.7	4.6	227
	G+GL+GAL	0.5	-0.4	-3.5	1.1	1.4	5.2	65
	GNSS	0.4	-0.4	-3.2	1.1	1.4	5.0	65

Table 4: Positioning error and RMS and convergence time for EBRE00 station for each solution

Station	**Case**	**Positioning Errors (cm)**			**RMS (cm)**			**Convergence time (Epoch)**
EBRE00		East	North	Up	East	North	Up	
	G	0.6	-0.8	-1.9	1.7	3.5	3.8	46
	GL	1.4	2.3	-0.2	2.2	2.9	2.2	523
	G+GL	1.1	-0.1	-1.9	1.8	1.7	4.2	151
	G+B	0.6	-0.9	-2.0	1.6	3.5	3.7	46
	GL + B	1.1	2.1	0.0	2.0	3	2.1	546
	G+GAL	0.9	-0.7	-2.0	2.1	2.5	4.4	43
	GL+GAL	1.1	2.2	-0.4	2.1	3	2.0	520
	GL+B+GAL	1.0	2.4	-0.6	2	3.1	2.1	547
	G+GAL+ B	0.9	-0.7	-2.1	2.1	2.5	4.5	44
	G+GL+ B	1.0	-0.1	-1.9	1.8	1.6	4.2	153
	G+GL+GAL	0.9	0.5	-1.3	2.0	2.2	4.0	68
	GNSS	0.9	0.5	-1.3	2.0	2.2	4.1	71

Table 5: Positioning error and RMS and convergence time for GANP station for each solution

Station	Case	Positioning Errors(cm)			RMS (cm)			Convergence time (Epoch)
		East	North	Up	East	North	Up	
GANP	G	0.2	-0.4	-5.6	1.8	2.3	6.3	57
	GL	1.6	1.4	-0.5	1.9	1.3	2.3	110
	G+GL	0.7	0.7	-4.0	1.8	1.1	5.0	89
	G+B	0.0	-0.3	-4.6	1.7	2.3	5.5	57
	GL + B	1.0	2.1	0.0	1.3	1.7	2.0	109
	G+GAL	0.2	0.0	-5.0	1.8	1.5	5.7	55
	GL+GAL	0.7	1.7	-1.1	1.7	1.7	2.3	101
	GL+B+GAL	0.5	2.1	-1.1	1.4	2	2.0	100
	G+GAL+ B	0.0	0.1	-4.3	1.8	1.5	5.1	55
	G+GL+ B	0.5	0.8	-3.4	1.7	1.2	4.5	89
	G+GL+GAL	0.5	0.8	-3.8	1.8	1.2	4.5	84
	GNSS	0.4	0.9	-3.4	1.7	1.2	4.2	84

Table 6: Positioning error and RMS and convergence time for KIRU station for each solution

Station	Case	Positioning Errors(cm)			RMS (cm)			Convergence time (Epoch)
		East	North	Up	East	North	Up	
KIRU	G	0.4	0.3	-2.4	1.7	1.4	3.8	95
	GL	2.5	-1.6	-3.6	2.3	2.5	4.2	86
	G+GL	1.2	-0.2	-2.9	1.6	1.4	4	35
	G+B	0.2	0.4	-2.1	1.6	1.3	3.5	95
	GL + B	1.9	-1.1	-2.4	1.7	2.3	3.1	86
	G+GAL	0.3	0.2	-1.6	1.6	0.7	3.4	79
	GL+GAL	2.1	-0.6	-3.1	2.2	1.5	4.3	80
	GL+B+GAL	1.7	-0.3	-2.5	1.8	1.4	3.7	78
	G+GAL+ B	0.1	0.2	-1.5	1.5	0.7	3.2	80
	G+GL+ B	1.0	-0.1	-2.7	1.5	1.3	3.7	35
	G+GL+GAL	1.1	-0.1	-2.5	1.6	1.1	3.8	34
	GNSS	1.0	0.0	-2.3	1.5	1.0	3.6	34

Table 7: Average Positioning error and RMS and convergence time for all station for each solution

Station	Case	Positioning Errors (cm)			RMS (cm)			Convergence time Epoch)
		East	North	Up	East	North	Up	
AVERAGE	G	0.3	-0.475	-3.6	1.7	2.475	4.775	60.5
	GL	1.9	0.475	-1.475	2.075	2	3.1	234.25
	G+GL	0.925	0.025	-3.1	1.575	1.5	4.675	85
	G+B	0.175	-0.45	-3.15	1.625	2.45	4.35	60.25
	GL + B	1.35	0.9	-1.125	1.575	2.1	2.6	237.5
	G+GAL	0.35	-0.35	-3.15	1.775	1.525	4.575	53
	GL+GAL	1.3	0.85	-1.775	2	1.7	3.05	191.5
	GL+B+GAL	1.05	1.2	-1.6	1.75	1.825	2.775	197.5
	G+GAL+ B	0.225	-0.325	-2.875	1.75	1.525	4.325	53.5
	G+GL+ B	0.75	0.05	-2.825	1.45	1.45	4.25	126
	G+GL+GAL	0.75	0.2	-2.775	1.625	1.475	4.375	62.75
	GNSS	0.675	0.25	-2.55	1.575	1.45	4.225	63.5

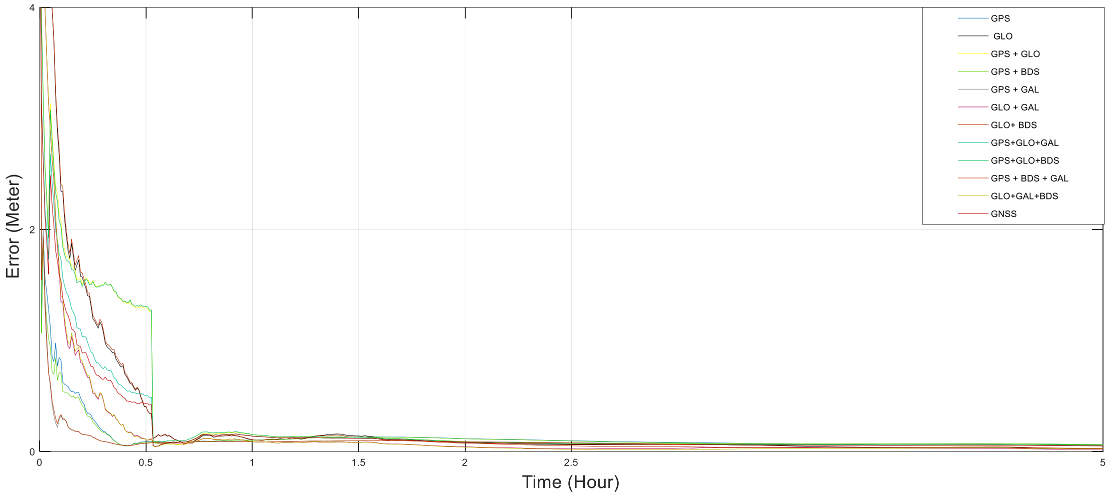

Figure 3: 3D positioning error at BOR1 station

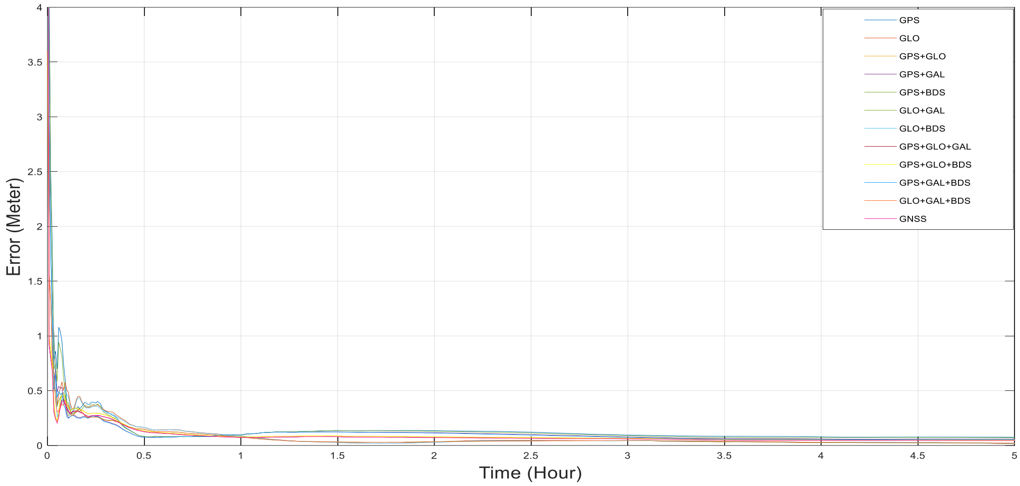

Figure 4: 3D positioning error at GANP station

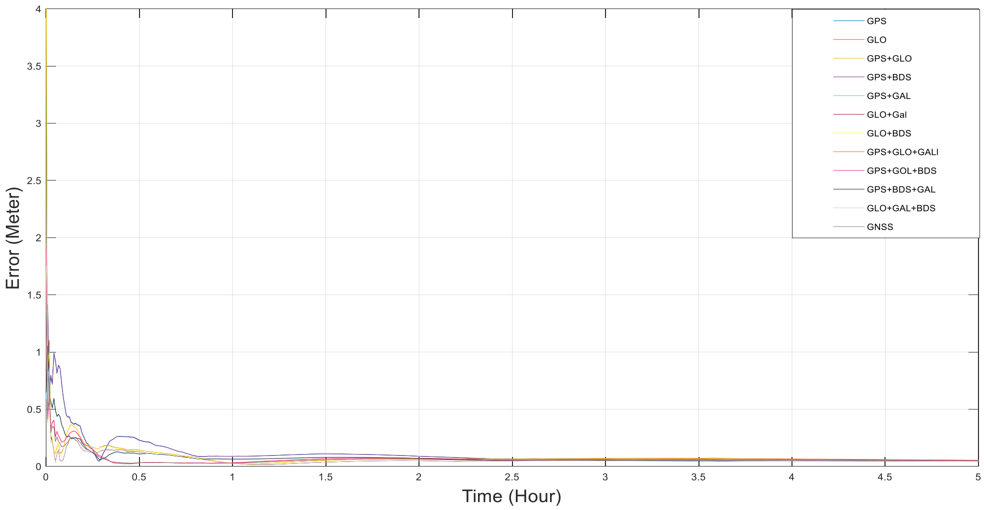

Figure 5: 3D positioning error at KIRU station

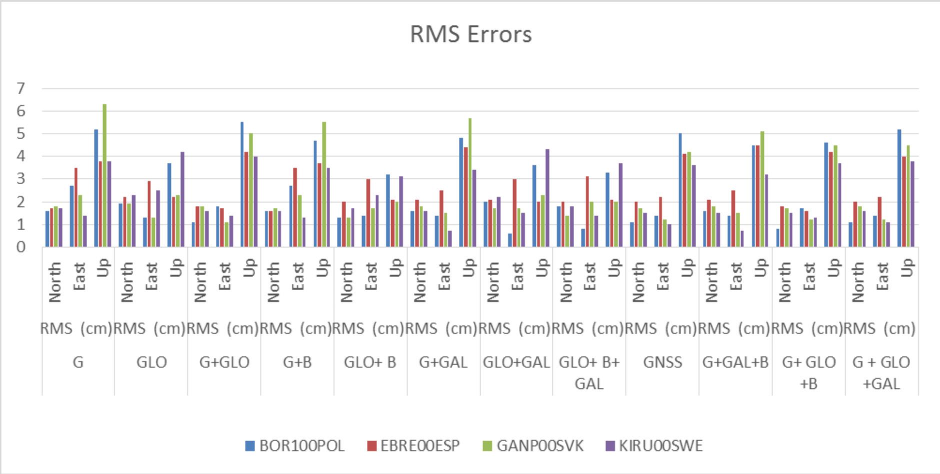

Figure 6: RMS cm errors at each station in N, E and up direction for all solutions

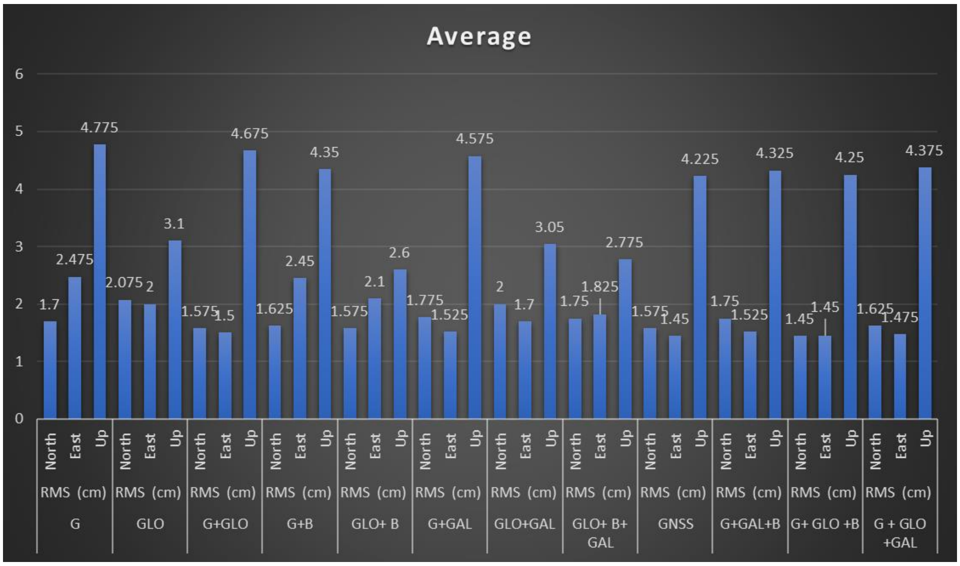

Figure 7: Average RMS errors at all station in N, E and up direction for all solutions

To investigate the effect of using the different GNSS combinations while using the PPP method, contrast experiments were tested by mixing dual-frequency ionospheric-free PPP models in static mode with G only, GLO only, G + GLO, G+ B, GLO+B, G+GAL, GLO+GAL, GLO+B+GAL, GNSS, G+GAL+B, G+GLO+B and G+GLO+GAL combination cases. The results of positioning errors, root mean square and convergence time in North, East and Up for each station, root mean square errors and convergence time are shown in Tables 2, 3, 4, and 5 for each station, Table 6 for the average Positioning error and RMS and convergence time for all station for each case of combination, Figures 2, 3, 4, and 5 show the 3D positioning errors within the observation duration for each MGEX station, Figure 6 shows the root mean square in North, East and up for each station and Figure 7 shows the average of them for each case. Overall, the combined of GPS and Galileo observation in PPP solution improves the convergence time and gives the shortest convergence time of the 12 study cases with average value 53 minute and with minimum value 35 minute. By comparing the root mean square error (RMS) values, the combination of G+GLO+B gives the minimum RMS error in North and East direction with minimum value 1.2 cm, maximum value 1.8 cm and average value1.45 cm, and the combination of GLO+GAL+B gives the minimum RMS errors in up directions with average value 2.775 cm and minimum 2.775 cm and maximum 4.5 cm

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4. Summary and Conclusions

Averaged Seven days observation data from 4 MGEX stations with 30 sec interval time and 8°elevation mask angle and with 12 cases of combination between different GNSS systems in static mode were tested and processed to investigate the positioning accuracy of the combination of different systems. The results indicate that the combination of different GNSS can enhance the PPP solution. The combined PPP has shown a significant convergence improvement in the case of using combined of G and GAL observation, while the positioning accuracy after convergence has no shown significant improvement. The result of G+GLO+B gives the minimum RMS error in North and East direction and the combination of GOL+GAL+B gives the minimum RMS errors in up directions. As the increasing in the working satellites in the sky will be continuous in the future, the combination and constellation of different GNSS will improve the PPP solution performance and mitigate the positioning errors and will aslo make an improvement in convergence time.

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