EASR

Engineering and Applied Science Research

https://www.tci-thaijo.org/index.php/easr/index

Published by the Faculty of Engineering, Khon Kaen University, Thailand

Evaluation of GNSS positioning accuracy from satellite-based augmentation systems in Thailand

Phunsap Thari, Somchai Kriengkraiwasin and Chalermchon Satirapod*

Department of Survey Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand

Received 8 May 2021
Revised 28 June 2021
Accepted 5 July 2021

Abstract

Satellite Based Augmentation System (SBAS) provides correction message services as an additional system to navigation satellites. Several SBAS services exist in many regions and usually cover a large area. Although, Thailand is not geographically located within a center of SBAS service coverage, users in Thailand can still receive correction messages from some available systems. This study aims to evaluate the GNSS positioning accuracy with corrections from different operational SBAS systems; namely, SPAN, GAGAN and BDSBAS when its positioning strategy is Single Point Positioning (SPP). The positioning results are then compared with solutions from Precise Point Positioning (PPP) which are referred to as reference coordinates. GNSS observations in this study are taken from 40 GNSS Continuously Operating Reference Stations (CORS) operated by the Royal Thai Survey Department. Certain period observations; comprising of September 2019, December 2019, and April 2020, are selected into computations. This research shows that three SBASs could not significantly improve both horizontal and vertical positioning accuracy comparing with GPS Single Point Positioning solutions.

Keywords: GNSS, SBAS, SPAN, GAGAN, BDSBAS

1. Introduction

Global Navigation Satellite System technology is continuously developed presently. Particulary, Global Positioning System (GPS) has been developed by the United States Department of Defense and is applicable for location identification. GPS signal currently covers everywhere in the world. GPS has long been utilized in various applications including cartography and control point, plate tectonic detection, atmospheric studies, cadastral surveying and precise timing [1-10]. Observables from GPS signal which are commonly used to determine positioning coordinates consist of 2 observables; pseudorange and carrier phase [11]. The single point positioning which is the absolute positioning using the pseudorange method can instantly provide the position coordinate with the positioning accuracy of 5-10 meters [12, 13]. With the intention to improve the positioning accuracy recently, Satellite Based Augmetation System (SBAS) had been developed accordingly. SBAS in each country will provide the different corrections that are suitable for each region. When such correction and GPS observation data are processed together, the positioning accuracy will be different and is subjected to the SBAS service provided in each country [14, 15] analysed performance of GPS Aided Geo Augmented Navigation (GAGAN) over Sri Lanka. The results showed that GAGAN corrections could improve the positional accuracy for a single frequency receiver. On the other hand, a previous study carried out by [16] revealed that the performance of GAGAN system is not suitable for Thai region. Currently, Thailand is not located within the service area, but still be able to receive correction signals from several SBASs namely SPAN [17], GAGAN [15] and BDSBAS [18]. Therefore, this reseach focusses on the assessment of positioning accuracy using SBAS corrections processed with GPS observation data for the single point positioning determination in Thailand. The data retrieved from 40 GNSS CORS operated by Royal Thai Survey Department in different time periods; during September 2019, December 2019 and April 2020, were used to analyse the performance of SBASs. The correction from SBAS were processed together and compared with the reference coordinates obtained from the Precise Point Positioning (PPP) technique.

2. Satellite based augmentation system (SBAS)

Satellite Based Augmentation System (SBAS) is the system that the Federal Aviation Administration of United States of America designed for aviation applications. As many countries in Europe also acknowledged the importance of such system, the development plan has been implemented in June 1996. Thereafter, further the development of the SBAS in Japan called Multifunctional Satellite Augmentation System (MSAS) has started in 2003 [19]. In general, the SBAS will provide the GNSS correction services including correction of orbit errors, correction of satellite clock errors, and correction of ionospheric errors to improve the positioning accuracy [16, 17] in large service-coverage area. Currently, the development of SBAS can be found in many countries across the globe as shown in Figure 1. Initial test results and analysis of 1st generation SBAS-like algorithm from the implementation of Asia-Pacific GNSS Test

*Corresponding author.
Email address: chalermchon.s@chula.ac.th
doi: 10.14456/easr.2022.23

Bed in Thailand were reported in [20] and [21]. Preliminary results obtained from the 2nd Generation Dual Frequency Multi-Constellation SBAS in Thailand were published in [22].

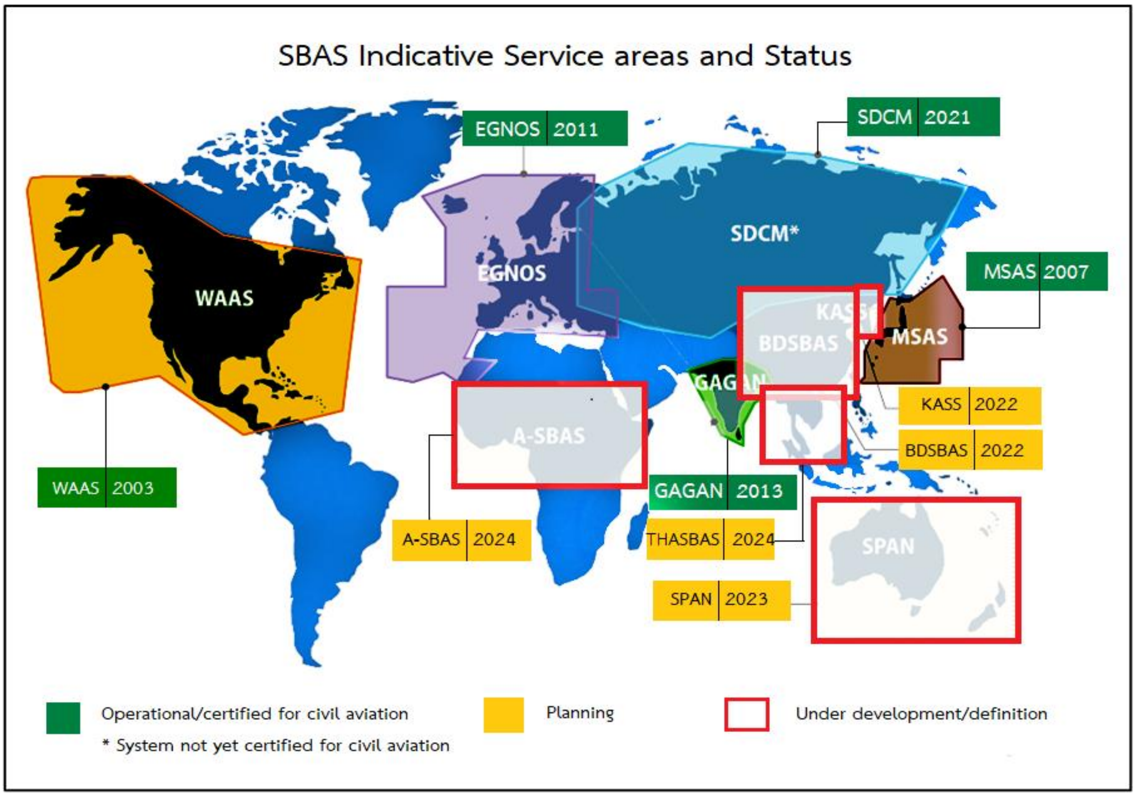

Figure 1 SBAS indicative service areas (modified from [23])

Since SBAS in each country has a similar system structure [19], in this paper, the BeiDou Satellite-Based Augmentation System (BDSBAS) was selected as an example for further explanation. BDSBAS is one type of SBAS developed by China PR which started to provide sevices via GEO-1 (BDSBAS PRN Signal Number 130) at latitude 80ºE on 9th November 2018 [18]. BDSBAS provides correction services including correction of orbit errors, correction of satellite clock errors, and correction of ionospheric errors to adjust the coordinates of itself [24]. The coverage area consists of China and nearby countries including Thailand. Available BDSBAS services have 2 modes which are single frequency and dual frequency services and multi frequency services corresponding to ICAOSARPs'standard which SF provides the correction to GPS on L1 C/A signal for aviation services [25].

Generally, BDSBAS has a ground segment which composes of Master Control Stations, Data Processing Stations, Monitoring Stations (MS), and Uplink Stations that spread thoroughly across China, as shown in Figure 2. Reference Stations and Ionospheric Grid Points (IGPs) of GAGAN and SPAN are shown in Figures 3 and 4 respectively. More details about BDSBAS, GAGAN and SPAN are explained in [26], [27] and [28]. SBAS' messages will be transferred via B1C and B2a signals to GEO satellite's users [18]. Furthermore, a space segment, comprising of 3 GEO satellites (at 80°E, 110.5°E and 140°E) and also a user segment [26] are as shown in Figure 5.

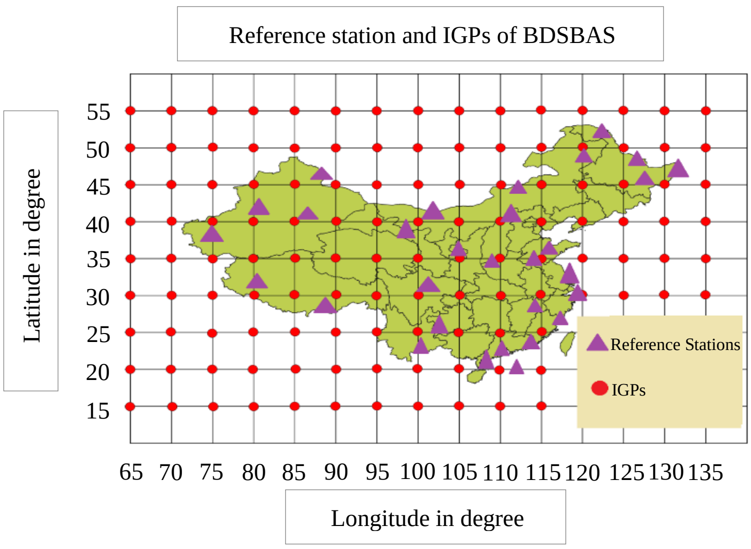

Figure 2 Reference stations and IGPs of BDSBAS

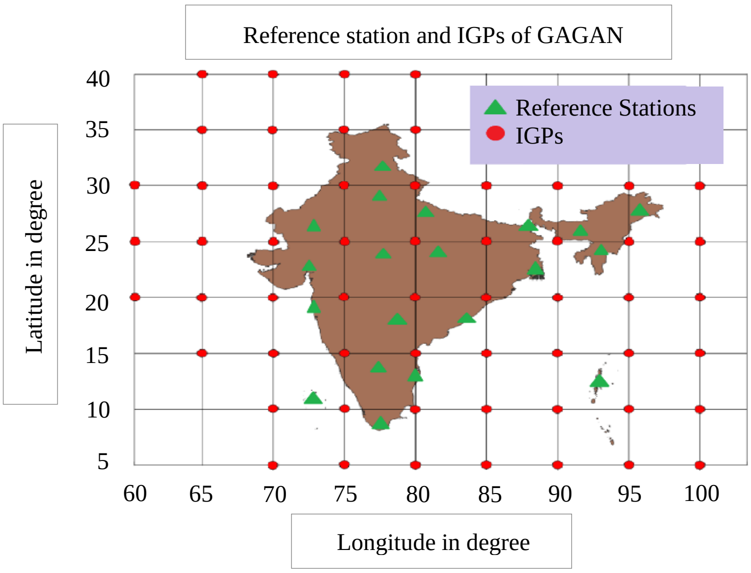

Figure 3 Reference stations and IGPs of GAGAN

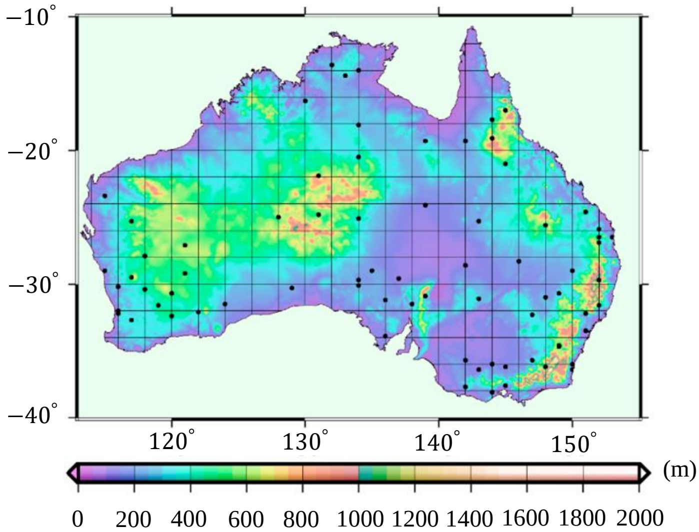

Figure 4 Reference stations and IGPs of SPAN [28]

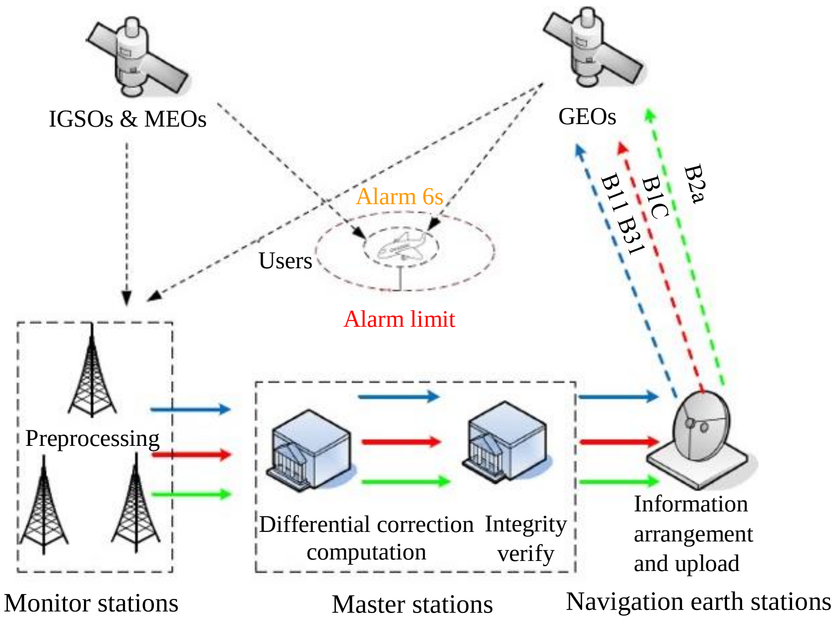

Figure 5 BDSBAS System architecture [18]

3. Methods and methodology

In order to evaluate the positioning accuracy, the correction obtained from SBAS has been processed together with the GPS observation data for the evaluation of the single positioning in accordance with the pseudorange measurement and then be compared with the data processed by the application of Precise Point Positioning (PPP) technique. In order to obtain accurate reference coordinates of all stations, the 7-day data sets for each station were processed using the PPP technique with the GipsyX software. The coordinates obtained from the GipsyX software should be accurate to within a centimeter. Therefore, the 7-day averaged coordinates of an individual station are used as reference coordinates for subsequent analysis. The Root-Mean-Squared Error has been used as a statistical method for data comparison which produced the Observation Equation and the Statistical Equation for comparing the results as provided below.

3.1 Single point positioning: SPP

Single point positioning (SPP) technique is the absolute positioning of the reciever by using only one receiver. The pseudorange measurement is generally used. Pseudorange obtained from the measurement might deviate from the actual distance between the satellite and the reciever because of various types of errors including orbit errors, satellite clock errors, and atmospheric errors etc. The pseudorange equation obtained from code observations was provided below in a unit of length [11]

$$R = \rho + \Delta r + d_{ion} + d_{trop} + c(dt - dT) + \varepsilon p + \varepsilon_R \quad (1)$$

where: R is the pseudorange code observation in range units (meter), ρ is the range between the receiver and satellite (meter), Δr is the orbital error (meter), d_{ion} is the ionospheric delay in range units (meter), d_{trop} is the tropospheric delay in range units (meter), c is speed of light (meter per second), dt is the receiver clock offset (second), dT is the satellite clock offset (second), εp is the multipath effects (meter), ε_R is the noise of the pseudorange measurements (meter).

3.2 Root mean squared error: RMSE

In this research, the Root-Mean-Squared Error (RMSE) has been introduced to evaluate the positioning accuracy in both horizontal and vertical directions, which provided in equation 2 and equation 3 respectively [29].

3.2.1 Horizontal positioning accuracy

$$RMSE_r = \sqrt{\frac{\Sigma\left(\left(N_{data,i} - N_{check,i}\right)^2 + \left(E_{data,i} - E_{check,i}\right)^2\right)}{n}} \quad (2)$$

where: $RMSE_r$ is horizontal positioning accuracy (meter), $N_{data,i}$, $E_{data,i}$ are coordinates of the ith check points in the dataset (meter), $N_{check,i}$, $E_{check,i}$ are coordinates of the ith check points from an independent source with higher measurement accuracy (meter), *i* is an integer ranging from 1 to *n*, *n* is the number of check points in the dataset.

3.2.2 Vertical positioning accuracy

$$RMSE_Z = \sqrt{\frac{\Sigma\left(Z_{data,i} - Z_{check,i}\right)^2}{n}} \quad (3)$$

where: $RMSE_Z$ is vertical positioning accuracy (meter), $Z_{data,i}$ is coordinates of the ith check point in the dataset (meter), $Z_{check,i}$ is coordinates of the ith check point from an independent source with higher measurement accuracy (meter), *i* is an integer ranging from 1 to n, *n* is the number of check points in the dataset.

3.3 Data used in this study

The GPS observation data are obtained from 40 CORSs operated by the Royal Thai Survey Department covering the entire area of Thailand as shown in Figure 6. SBAS corrections are provided by the Navigation and Time Monitoring Facility (NTMF)(CNES NTMF located in Toulouse, France) covering the whole nation. Measurements have been recorded every second for 3 months of 1st-30th September 2019, 1st-31st December 2019, and 1st-30th April 2020. The collected data has been further processed with RTKLIB ver.2.4.2 [30] and compared. Their positioning accuracy is determined using the Root-Mean-Squared Error (RMSE) as the statistical methodology as described below.

Comparisons between Precise Point Positioning (PPP) and $GPS_{(SPP)}$ solutions

Comparisons between Precise Point Positioning (PPP) and combined $GPS_{(SPP)}$ and $SBAS_{(SPP)}$ correction solutions

4. Results

Computed single point positioning (SPP) accuracies are evaluated based on combined data from SBAS corrections and GPS observables of selected 40 RTSD CORS. They are later compared with the assigned reference coordinates using Precise Point Positioning (PPP) GPS observations. The results are described below for every entire three-month observations starting from September 2019, December 2019, and April 2020.

As of September 2019, the processed positioning results obtained from GPS 40 CORS observables and GAGAN127 corrections give averaged horizontal and vertical positioning accuracy (in terms of RMSEs) of 1.22 and 1.60 meters respectively. When identical

GPS measurements are performed but GAGAN128 corrections are applied, averaged horizontal and vertical positioning accuracy become 1.21 and 1.55 meters accordingly. However, when GPS 40 CORS observables are only used in SPP determinations, it is found that the averaged horizontal and vertical positioning RMSEs are 1.09 and 1.95 meters. Computed results are as presented in Figure 7 and Figure 8. Their comparisons are shown in Table 1.

As of December 2019, the processed positioning results obtained from GPS 40 CORS observables and GAGAN127 correction messages provide horizontal and vertical positioning accuracy of averagely 1.03 and 1.38 meters accordingly where as if GAGAN128 corrections are applied, their horizontal and vertical positioning accuracy are averagely 1.04 and 1.37 meters.

BDSBAS could be observed at only 31 ground stations therefore only 31 GPS CORSs are used in the computations. When corrections are received from BDSBAS130 satellites, averaged horizontal and vertical positioning accuracies are 6.06 and 5.35 meters. However, by using only the observable data of GPS (SPP) from 40 stations, the value of RMSE for the averaged horizontal and vertical positioning accuracy are 0.97 and 2.66 meters. All data are plotted in Figure 9, Figure 10, and shown in Table1.

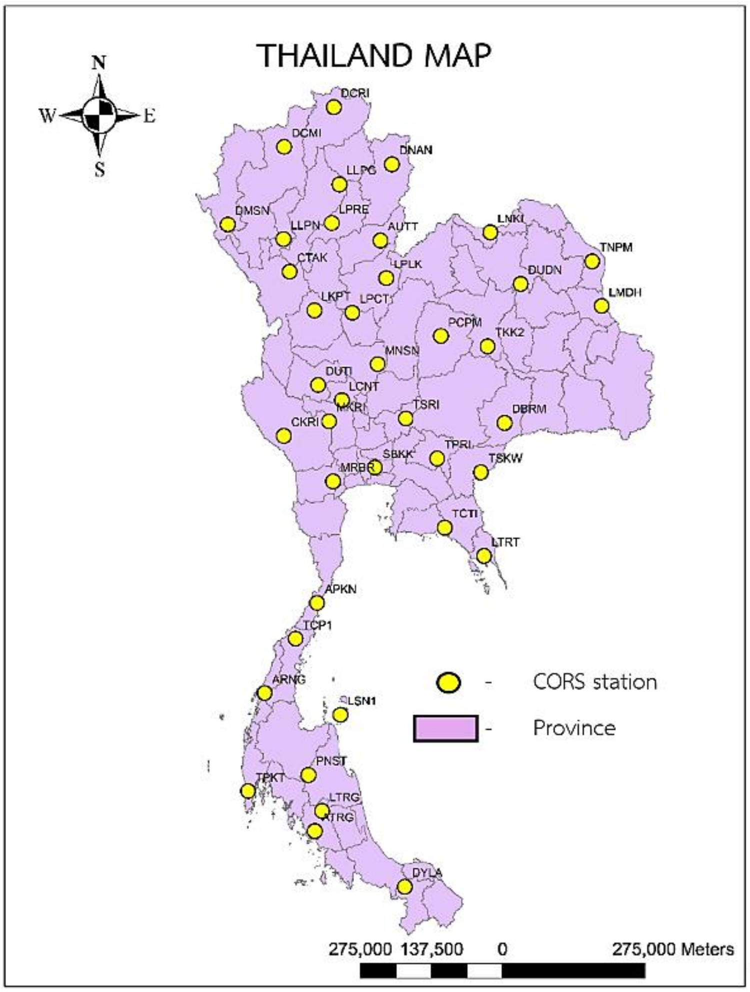

Figure 6 CORS Locations operated by the royal Thai survey department

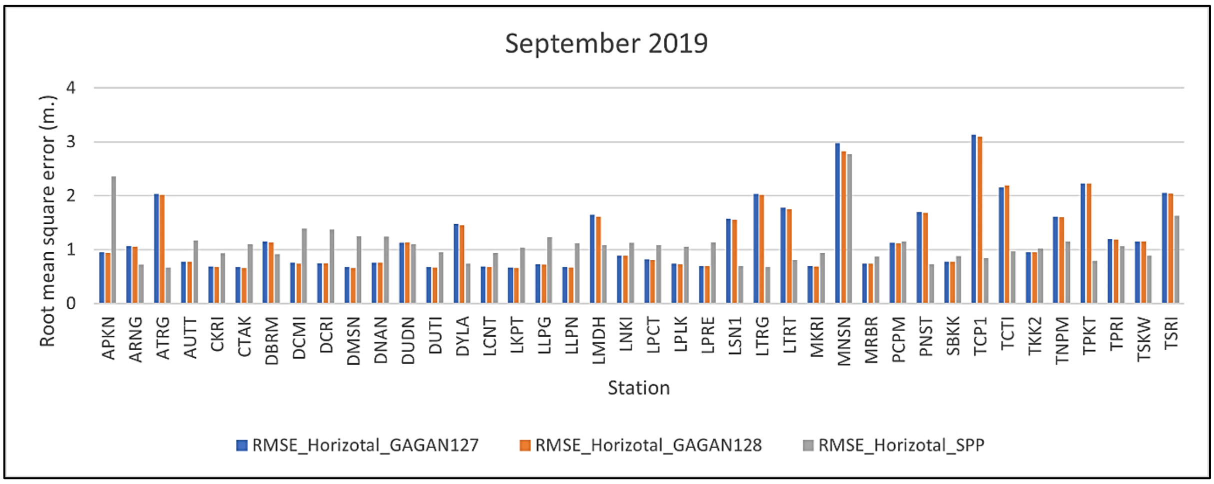

Figure 7 RMSE of horizontal positioning accuracy at each station in September 2019

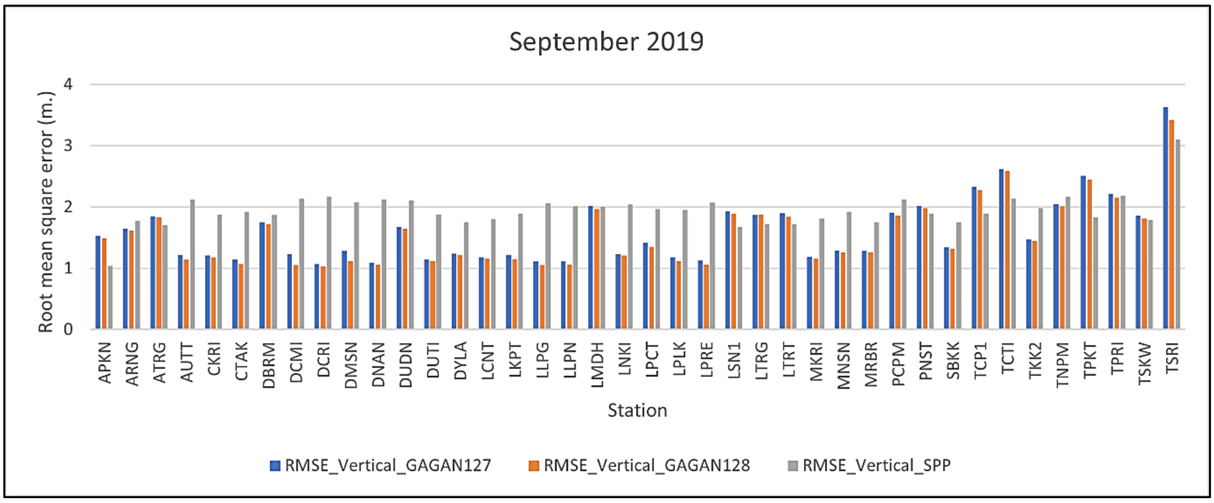

Figure 8 RMSE of vertical positioning accuracy at each station in September 2019

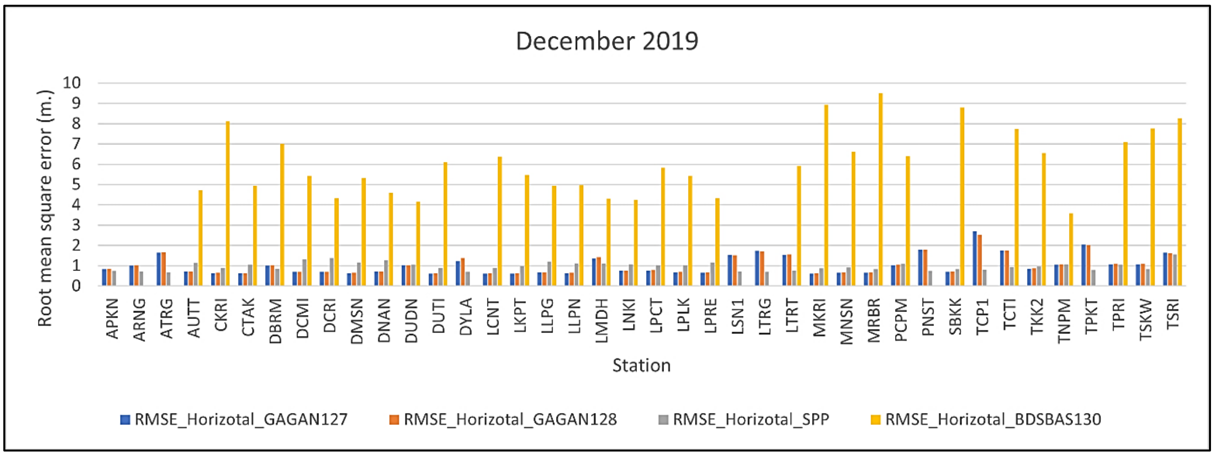

Figure 9 RMSE of horizontal positioning accuracy at each station in December 2019

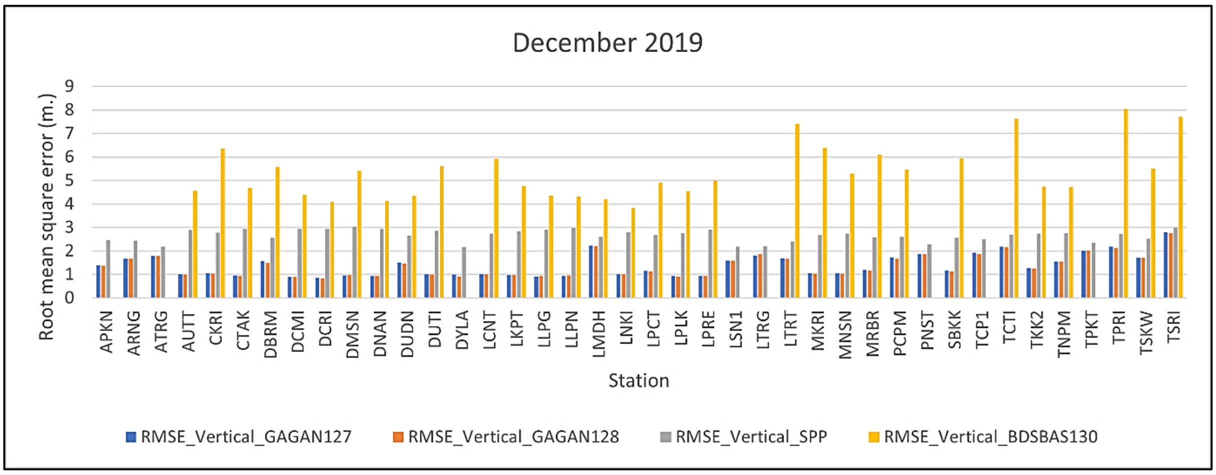

Figure 10 RMSE of vertical positioning accuracy at each station in December 2019

As of April 2020, SPAN could be observed at only 11 reference stations. The computed results of GPS observations and SPAN122 satellite corrections provides averaged horizontal and vertical RMSE of 2.27 and 2.07 meters accordingly.
By using GAGAN127 satellite corrections and GPS measurements at 40 stations, averaged horizontal and vertical RMSEs are 0.98 and 1.60 meters and by using GAGAN128 satellite corrections, their averaged horizontal and vertical RMSEs are 0.98 and 1.60 meters. With only GPS observations (SPP) from these 40 stations, the averaged RMSEs for horizontal and vertical accuracy are 1.02 and 1.95 meters. All computed data are plotted as shown in Figure 11, Figure 12 and shown in Table 1.

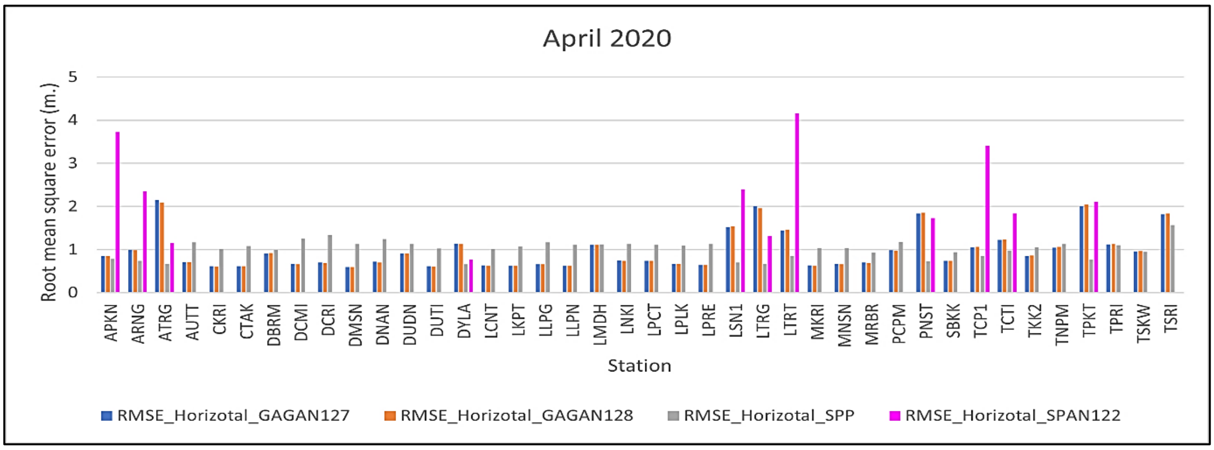

Figure 11 RMSE of horizontal positioning accuracies at each station in April 2020

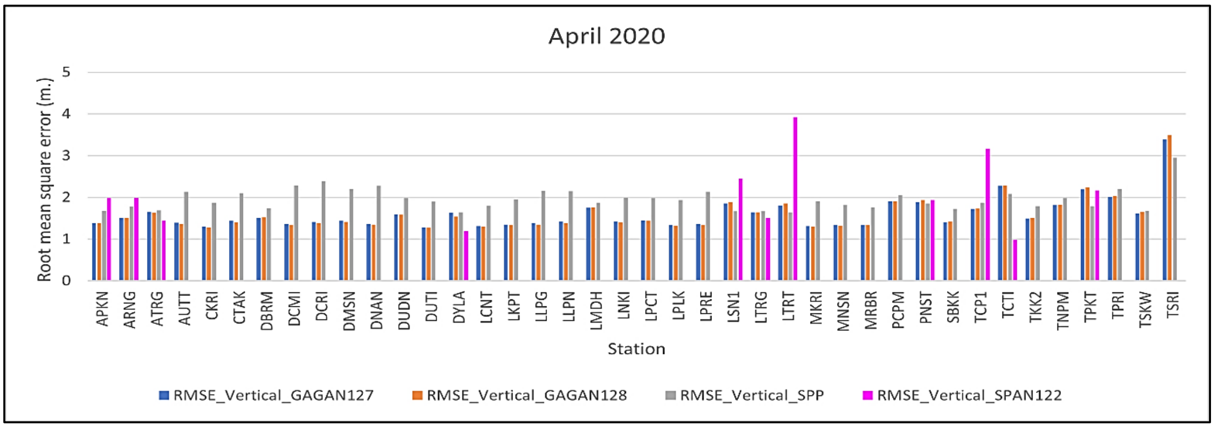

Figure 12 RMSE of vertical positioning accuracies at each station in April 2020

Table 1 Positioning accuracy of each test case

Time periods	*Statistics*	*Cases*				
		GPS only	***GPS+SPAN PRN122***	***GPS+GAGAN PRN127***	***GPS+GAGAN PRN128***	***GPS+BDSBAS PRN130***
September 2019	RMSE Horizontal (m.)	1.09	-	1.22	1.21	-
	RMSE Vertical (m.)	1.95	-	1.60	1.55	-
December 2019	RMSE Horizontal (m.)	0.97	-	1.03	1.04	6.06
	RMSE Vertical (m.)	2.66	-	1.38	1.37	5.35
April 2020	RMSE Horizontal (m.)	1.02	2.27	0.98	0.98	-
	RMSE Vertical (m.)	1.95	2.07	1.60	1.60	-
Average	RMSE Horizontal (m.)	1.03	2.27	1.08	1.08	6.06
	RMSE Vertical (m.)	2.19	2.07	1.53	1.51	5.35

5. Discussions

In this research, a total of 40 GNSS CORS stations were used to cover every part of Thailand. In order to investigate an effect of season on positioning results, three different periods of GNSS CORS data, April, September and December were selected. The entire one-month data starting from the beginning of each period at each station were used in this study. This is to ensure that sufficient amount of data was used to draw a solid conclusion from this research. In relation to Table 1, the following comments can be made:

The accuracy of GPS only solutions are similar for all three different periods. According to [31], the accuracy of GPS only solutions is approximately the same as the results obtained from this study. GPS only solutions were found to be consistent with the known coordinates at the 1-meter level in the horizontal component. However, it should be noted that the vertical accuracy of GPS only solutions in December is slightly worse than those obtained from April and September periods. Further investigations are therefore needed.

Based on the GPS+SPAN and GPS+BDSBAS solutions, the degradation of accuracy in both the horizontal and vertical components becomes more pronounced. These results are aligned with our expectation since the coverage areas are quite far away from Thailand. In case of GPS+GAGAN solutions, it was found that there is no significant improvement in the horizontal component but there is a slight improvement in the vertical component. These results are consistent with the conclusion made by [16].

6. Concluding remarks

Thailand currently could be able to receive signals from 3 SBASs including SPAN, GAGAN, and BDSBAS. Correction messages from these 3 available systems could not significantly improve GNSS horizontal positioning results. It is clearly shown that SPAN and BDSBAS correction messages could not improve their vertical positioning results whilst obtained GAGAN correction messages could improve the vertical positioning results based on positioning solution comparisons with the GPS Single Point Positioning results. In terms of signal availability, GAGAN signals could be received by 40 GNSS reference stations widely distributed in Thailand whilst SPAN and BDSBAS signals could only be obtained by 11 and 31 stations out of 40 stations, respectively covering only some parts of Thailand. To significantly improve SBAS solutions in Thai region, a close collaboration with any existing SBAS service provider should be established so that selected GNSS CORS in Thailand can be included as an extended part of existing SBAS services.

7. Acknowledgments

The authors would like to thank Royal Thai Survey Department for providing the GPS CORS data used in this study. The help from Dr. Chaiyut Charoenphon is gratefully acknowledged. Our special thanks are extended to Dr. Thayathip Thongtan of National Institute of Metrology, Thailand, for her valuable suggestions and numerous supports.

8. References

[1] Satirapod C, Homniam P. GPS precise point positioning software for ground control point establishment in remote sensing applications. J Survey Eng. 2006;132(1):11-4.
[2] Panumastrakul E, Simons W, Satirapod C. Modelling post-seismic displacements in Thai geodetic network due to the Sumatra-Andaman and Nias earthquakes using GPS observations. Surv Rev. 2012;44(324):72-7.
[3] Mustafar MA, Simons WJF, Tongkul F, Satirapod C, Omar KO, Visser P. Quantifying deformation in north borneo with GPS. J Geodes. 2017;91(1):1241-59.
[4] Suwantong R, Srestasathiern P, Satirapod C, Chuang S, Kitpracha C. Mean atmospheric temperature model estimation for GNSS meteorology Using AIRS and AMSU data. Eng Appl Sci Res. 2017;44(1):46-52.
[5] Trakolkul C, Satirapod C. Variations of precipitable water vapor using GNSS CORS in Thailand. Surv Rev. 2021;53(376):90-6.
[6] Charoenphon C, Satirapod C. Improving the accuracy of real-time precipitable water vapour using country-wide meteorological model with precise point positioning in Thailand. J Spatial Sci. In press 2020.
[7] Trakolkul C, Satirapod C. Analysis of PWV derived from the GNSS CORS stations for determining the onset of the southwest monsoon in Thailand. Int J Geoinformatics. 2020;16(2):71-8.
[8] Charoenkalunyuta T, Satirapod C, Keitniyomrung V, Yomwan P. Performance of network-based RTK GNSS for the cadastral survey in Thailand. Int J Geoinformatics. 2019;15(3):13-9.
[9] Thongtan T, Tirawanichakul P, Satirapod C. Precise receiver clock offset estimations according to each global navigation satellite systems (GNSS) timescales. Artif Satellite. 2017;52(4):99-108.
[10] Pothikunkupatarak N, Thongtan T, Satirapod C. Estimations of GNSS receiver internal delay using precise point positioning algorithm. J Appl Geodes. 2019;13(1):41-6.
[11] Rizos C. Principles and practice of GPS surveying. Kensington: School of Geomatic Engineering, University of New South Wales; 1997.
[12] Satirapod C, Rizos C, Wang J. GPS single point positioning with SA off: how accurate can we get?. Surv Rev. 2001;36(282): 255-62.
[13] Ernst & Young Global Limited. SBAS Test-bed demonstrator trial economic benefits report. Australia: EY; 2019.
[14] Choy S, Kuckartz J, Dempster A, Rizos C, Higgins M. GNSS satellite-based augmentation systems for Australia. GPS Solut. 2017;21(3):835-48.
[15] Dammalage D, De Silva D, Satirapod C. Performance analysis of GPS aided geo augmented navigation (GAGAN) Over Sri Lanka. Eng J. 2017;21(5):305-14.
[16] Pungpet P, Kitpracha C, Promchot D, Satirapod C. Positioning accuracy analyses on GPS single point positioning determination with GAGAN correction services in Thailand. Proceedings of 15th International Conference on Electrical Engineering/ Electronics, Computer, Telecommunications and Information Technology (ECTI-CON); 2018 July 18-21; Chiang Rai, Thailand. 2018. Thailand: ECTI; 2018. p. 724-7.
[17] Wu J, Wang K, El-Mowafy A. Preliminary performance analysis of a prototype DFMC SBAS service over Australia and Asia-Pacific. Adv Space Res. 2020;66(6):1329-41.
[18] Li R, Zheng S, Wang E, Chen J, Feng S, Wang D, et al. Advances in BeiDou navigation satellite system (BDS) and satellite navigation augmentation technologies. Satell Navig. 2020;1:1-23.
[19] Dautermann T. Civil air navigation using GNSS enhanced by wide area satellite based augmentation systems. Progr Aero Sci. 2014;67:51-62.
[20] Pringvanich N, Satirapod C. Performance of SBAS algorithm through the implementation of the Asia-Pacific GNSS test bed: initial study in Thailand. J Navigation. 2007;60(3):363-71.
[21] Pringvanich N, Satirapod C. Flight test results and analysis of SBAS-like algorithm from the implementation of the asia-pacific GNSS test bed. Aeronaut J. 2009;113(1139):35-40.
[22] Satirapod C, Khasuwan P, Vongsantivanich W, Chaimatanan S, Jackson R, Biegert D. Preliminary results obtained from the 2nd generation dual frequency multi-constellation SBAS in Thailand. Proceedings of 27th IUGG General Assembly; 2019 July 8-18; Montreal, Canada; 2019.
[23] European GNSS Agency. GNSS User technology report issue 3. Czech Republic: Office of the European Union; 2020.
[24] Liu C, Zhu W, Xu A, Kong Y, Jiang Y, Hu C. Performance evaluation method for ionospheric grid information of BDS via dual-frequency observations. IOP Conf Earth Environ Sci. 2019;237(6):062004.
[25] Bao J, Li R, Liu Y, Lui Y, Shao B. Ionospheric anomaly detection to support the BDSBAS. IEEE Access. 2019;8:1691-704.

[26] Chen S, Jin B, Li D, Qu P. Study on the prediction method of single and dual frequency service area for BDSBAS. In: Sun J, Yang C, Yang Y, editors. Proceedings of China Satellite Navigation Conference (CSNC); 2019 May 22-25; Beijing, China. New York: Springer; 2019. p. 228-37.
[27] Dammalage T. Application of Indian space-based augmentation service on geospatial data collections in Sri Lanka. Surv Rev. 2019;51(369):485-91.
[28] Li W, Zhao D, Shen Y, Zhang K. Modeling Australian TEC maps using long-term observations of Australian regional GPS network by artificial neural network-aided spherical cap harmonic analysis approach. Rem Sens. 2020;12(23):3851.
[29] Federal geographic data committee. Geospatial positioning accuracy standards part 3: national standard for spatial data accuracy. USA: National Spatial Data Infrastructure; 1998.
[30] Takasu T. RTKLIB: An open source program package for GNSS positioning [Internet]. 2013 [cited 2020 April 20]. Available from: http://www.rtklib.com/.
[31] Prakanrattana K, Satirapod C. Comparative study of using different ionosphere models in Thailand for single-frequency GNSS users. Surv Rev. 2019;51(366):213-8.