THE JOURNAL OF NAVIGATION (2007), **60**, 363–371.
doi:10.1017/S0373463307004274 Printed in the United Kingdom

SBAS Algorithm Performance in the Implementation of the ASIAPACIFIC GNSS Test Bed

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This paper discusses the preliminary performance analysis result of the Asia-Pacific Global Navigation Satellite Systems (GNSS) Test Bed. Currently, seven Asia-Pacific economies are participating in the Test Bed project, namely Australia, Chinese Taipei, Indonesia, Malaysia, the Philippines, Thailand and Vietnam. The Test Bed was commissioned in May 2006. The discussion topics in this paper include Test Bed system architecture and preliminary analysis of the system performance. As presented in this paper, while current Satellite-Based Augmentation System (SBAS) algorithms can improve the accuracy performance of GPS positioning results, it cannot fulfill the integrity performance required by civil aviation community. This paper analyzes the limitation of the algorithm and proposes future research topics related to the limitation.

KEY WORDS

1. GPS. 2. GNSS Test Bed. 3. SBAS.

1. INTRODUCTION. The Asia-Pacific GNSS Test Bed is a regional collaborative programme that brings together experts in satellite navigation within the Asia-Pacific to study the performance of the Global Navigation Satellite System (GNSS) and to develop a regional plan that will lead to a successful implementation of GNSS in the region. The programme is a work programme under the APEC GNSS Implementation Team (APEC GIT), a working group established under the Asia-Pacific Economic Cooperation (APEC). The programme receives a supporting grant from the United States Trade and Development Agency (USTDA), on which Thailand, through Aeronautical Radio of Thailand (AEROTHAI), acts as the Grantee. Currently, seven Asia-Pacific economies are participating in the Test Bed programme namely, Australia, Chinese Taipei, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam. This Asia-Pacific GNSS Test Bed is designed to serve the following five strategic objectives: 1) to evaluate GNSS augmentation capability in the Asia-Pacific region; 2) to collect empirical GNSS data and to analyze equatorial atmospheric effects on GNSS performance; 3) to allow participating economies to attain hands-on working experiences with GNSS equipments; 4) to allow participating economies to refine and validate GNSS performance over their Flight Information Regions; 5) to establish a stage for regional research

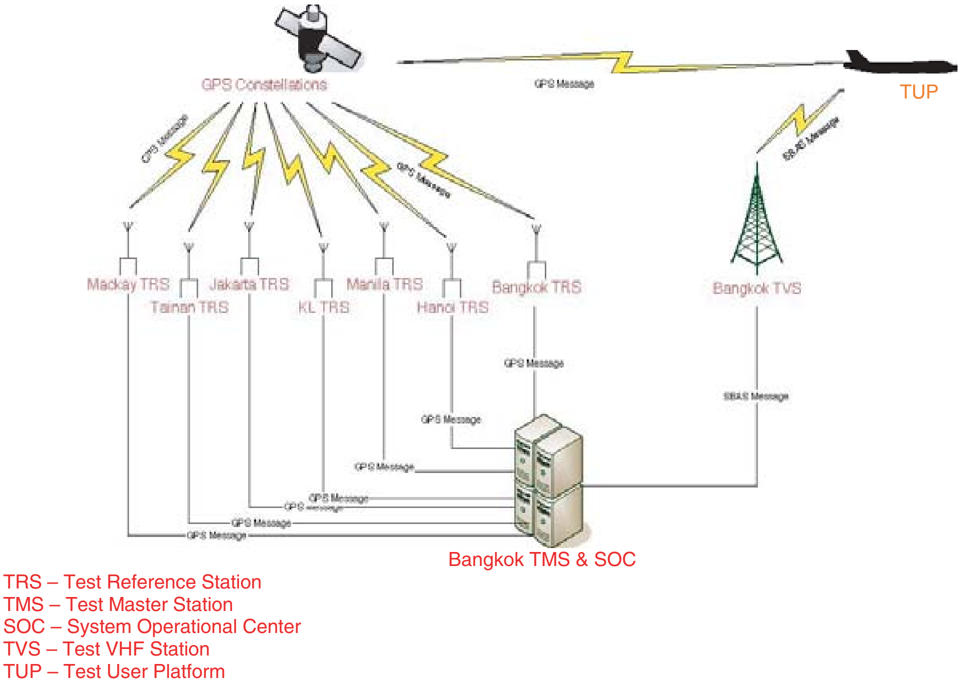

Figure 1. High level architecture of the Asia-Pacific GNSS Test Bed.

collaborations for the Asia-Pacific. More details on data collection and the performance assessment plan of the programme can be found in Pringvanich and Abhakara (2005a) and Pringvanich et al. (2005).

This paper is organised as follows. The components and architecture of the Test Bed are briefly described. Then, the performance analysis of GPS positioning results obtained from the Test Bed is presented. Finally, a conclusion and discussion on future works are given in Section 4.

2. TEST BED COMPONENTS AND ARCHITECTURE.

The Test Bed reflects hybrid architecture between a Satellite-Based Augmentation System (SBAS) and a Ground-Based Augmentation System (GBAS). While the Test Bed algorithm and calculations are based on SBAS methodology, it will broadcast SBAS messages using GBAS VHF data link. A high level architecture of the Test Bed is illustrated in Figure 1. The Test Bed consists of four main components, the reference, master and VHF stations and the user platform.

2.1. *Test Reference Station* (*TRS*). The TRS monitors the GPS constellation from a surveyed location and collects GPS signals. Each TRS consists of a dual-frequency GPS receiver, a network time protocol server, a computer, communication interface hardware, and a data archival hardware. After receiving GPS signal and messages, each TRS transfers its data to the Test Master Station (TMS) through a data network. As part of the funding supported by USTDA, five TRS are installed throughout Southeast Asia. The five locations are Jakarta (Indonesia), Kuala Lumpur (Malaysia), Manila (the Philippines), Bangkok (Thailand), and Hanoi

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(Vietnam). Two additional economies, Australia and Chinese Taipei, have installed their own TRS in Mackay and Tainan, respectively.

2.2. *Test Master Station*. The TMS maintains communications with all the TRS connected to the architecture. After receiving GPS data from each TRS, TMS will process pseudorange and navigation data, perform a wide-area differential GPS algorithm, and generate SBAS messages. TMS will then transmit the SBAS messages to the Test VHF Station (TVS). Moreover, TMS is responsible for archiving GNSS and SBAS data and for displaying the system performance.

2.3. *Test VHF Station*. TVS broadcasts SBAS messages received from the TMS to an airborne Test User Platform (TUP) via a VHF transmitter. It maintains communication with the TMS. The TVS consists of a VHF broadcasting antenna, a single-frequency GPS receiver, a network time protocol server, a computer, and a router.

2.4. *Test User Platform*. The TUP will be installed on a test flight aircraft during flight tests. It may also be used to conduct static (non-flight) testing. The TUP consists of a dual-frequency GPS receiver, a VHF receiving antenna, a network time protocol server, and a computer. After receiving GPS signals from the GPS constellation and SBAS messages from the TVS, the TUP will decode GPS and SBAS messages and then calculate navigation solutions and integrity protection levels.

3. PRELIMINARY PERFORMANCE ANALYSIS.

3.1. *Test Configuration*. This performance analysis was carried out during August 14th–15th, 2006. The test configuration consisted of four test reference stations, located in Tainan, Kuala Lumpur, Manila and Bangkok. GPS data observed at each TRS were transmitted to the TMS via an internet Virtual Private Network (VPN) connection. The TVS transmitted SBAS messages to the TUP at 115·3 MHz. The test configuration is presented in Figure 2. During this testing, a TUP was installed statically at a Bangkok site. Data collection was conducted from 7am August, 14th to 7am August, 15th Bangkok local time (GMT + 7:00) using a one-second sampling interval. Accuracy, integrity and availability performances were assessed using data observed or calculated at the TUP.

3.2. *Satellite Availability*. The Dilution of Precision (DOP) values and number of satellites observed at the TUP during the data collection period are plotted in Figure 3. As seen in Figure 3, the TUP received a minimum of seven GPS satellites and had the highest PDOP value of 3·1. The satellite availability and geometry reflect a typical GPS availability and geometry seen in Bangkok, Thailand. This satellite availability also implies the possibility of using Fault Detection (FD) and Fault Detection and Exclusion (FDE) algorithms, which require a minimum of five and six satellites in view, respectively. The implication is especially important for the civil aviation community since FD and FDE algorithms can increase the integrity of GNSS-based navigation as part of Aircraft-Based Augmentation System (ABAS).

3.3. *Accuracy Performance*. The discrepancies in the three coordinate components relative to the known coordinates were calculated. The distribution and statistics of positioning errors in the horizontal and vertical components were then calculated and are shown in Figure 4. The standard deviations of horizontal and vertical errors are 0·92 and 2·85 metres, respectively. For the civil aviation

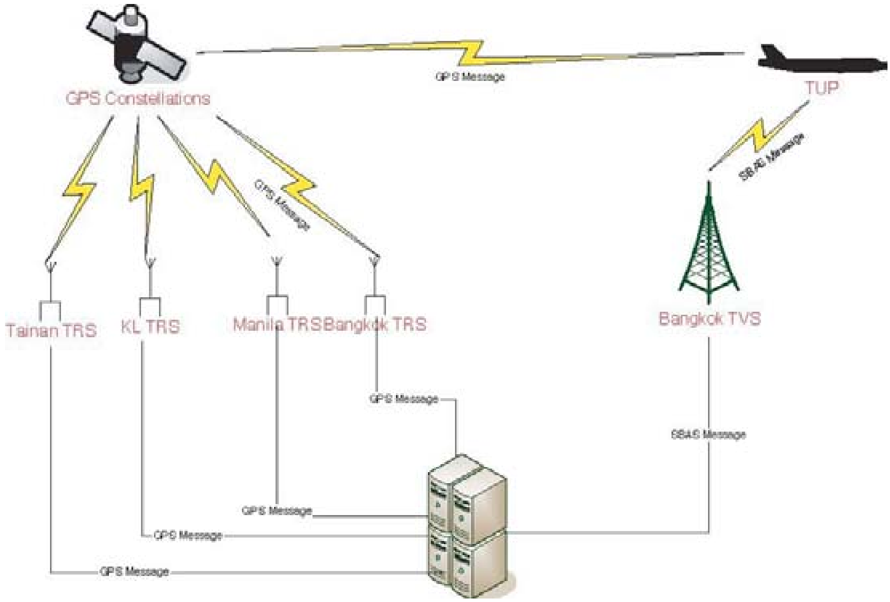

Figure 2. Test configuration.

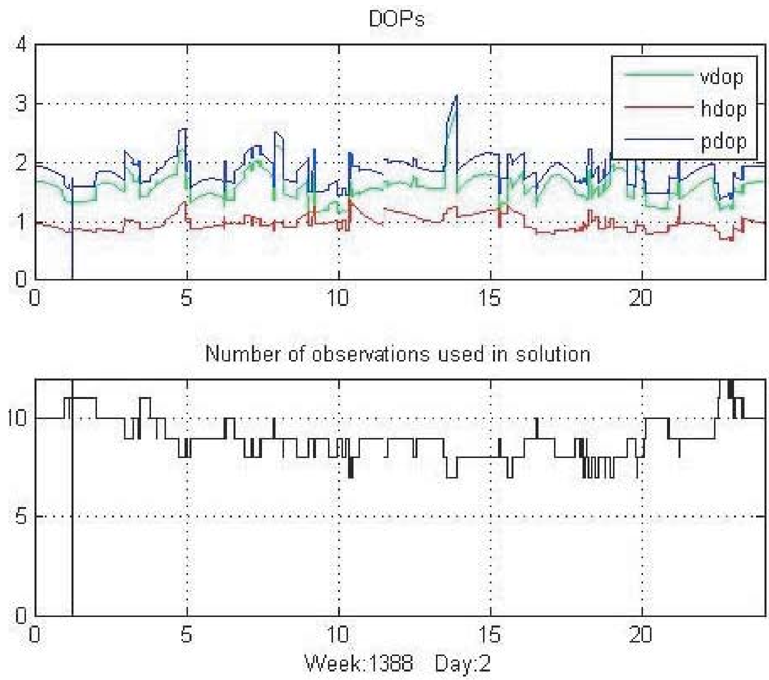

Figure 3. Satellite availability and Dilution of Precision (DOP) at TUP.

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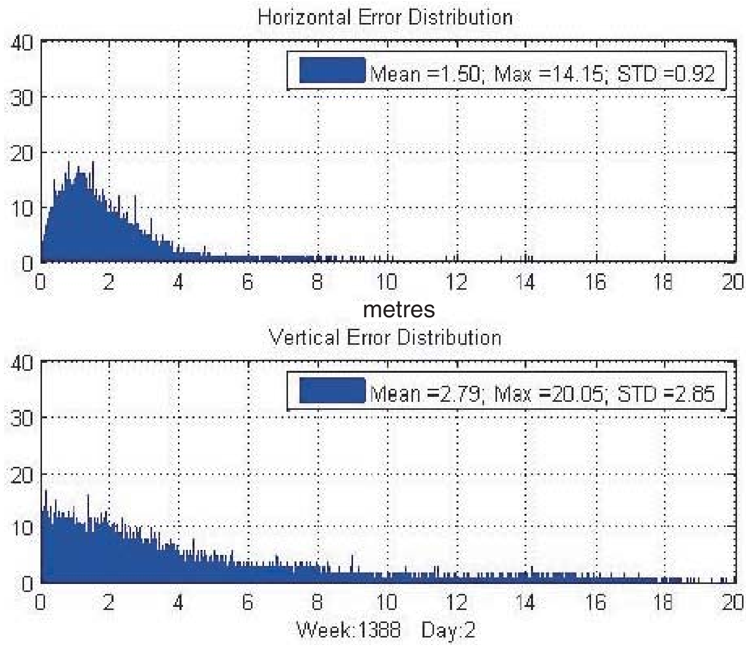

Figure 4. Distribution and statistics of horizontal and vertical positioning errors.

community, according to ICAO (2002), these accuracy performances satisfy the accuracy performance for Approach with Vertical Guidance-II (APV-II) operations.

3.4. *Integrity Performance*. Time-series plots of horizontal errors, horizontal protection levels (HPL), vertical errors, and vertical protection levels (VPL) are presented in Figure 5. The calculations of HPL and VPL are defined in ICAO (2002) and RTCA (2001), and the importance of protection levels is discussed in details in Pringvanich and Abhakara (2005b). As shown on the figure, some integrity failures (protection levels less than errors) occurred. For the horizontal component, the integrity failures mostly occur within short periods. These horizontal integrity failures may be caused by a multipath effect as there is a tall building rising above the observing site. Further investigation is therefore needed to confirm the source of these integrity failures.

For the vertical component, however, longer periods of integrity failures are observed (i.e. between 7:00–8:00 GPS time). Since these vertical integrity failures occur during a high-ionospheric-delay period, further investigation on how well SBAS algorithm can estimate ionospheric delay, especially on the range domain, becomes necessary future work.

3.5. *Availability Performance*. According to ICAO (2002), navigation using GNSS is available if and only if both accuracy and integrity requirements for the intended operation are satisfied. Figures 6 and 7 show the availability of APV-I operation, observed at the TUP, to be 99·852% and 99·968% for horizontal and vertical navigation, respectively. This result satisfies the availability requirement for APV-I operation.

Figures 8 and 9 show the availability of APV-II operation, observed at the TUP, to be 99·852% and 96·808% for horizontal and vertical navigation, respectively.

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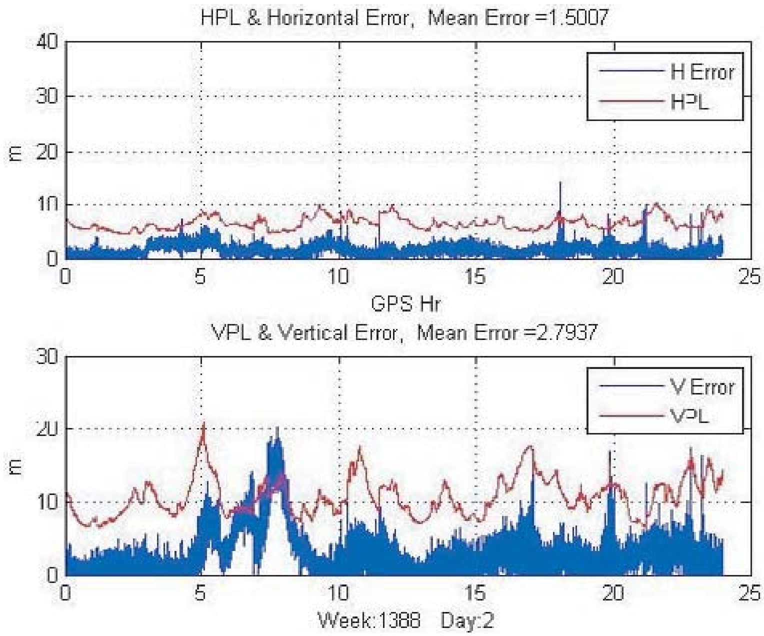

Figure 5. Positioning errors and protection levels.

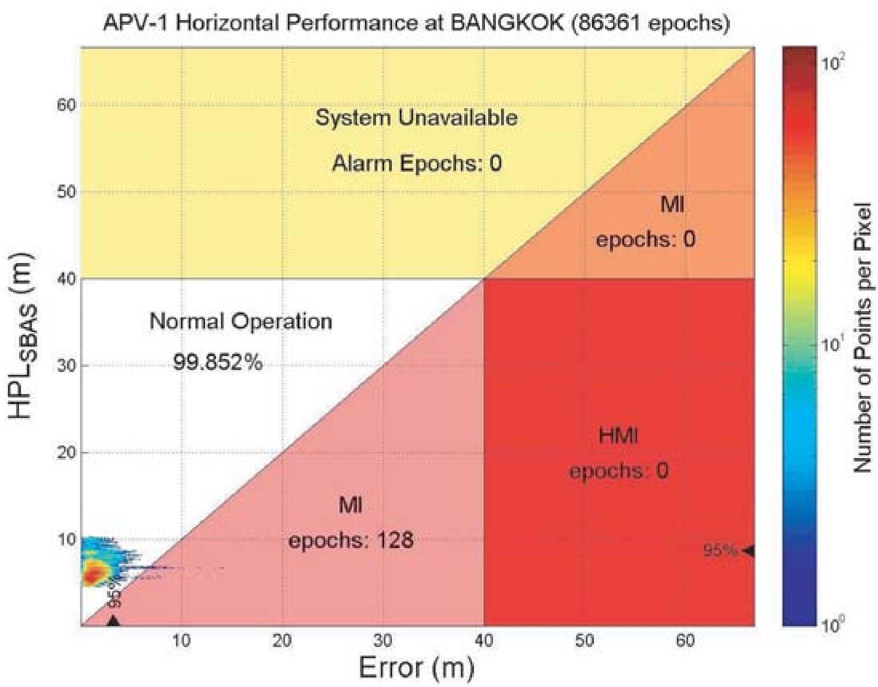

Figure 6. APV-I horizontal performance.

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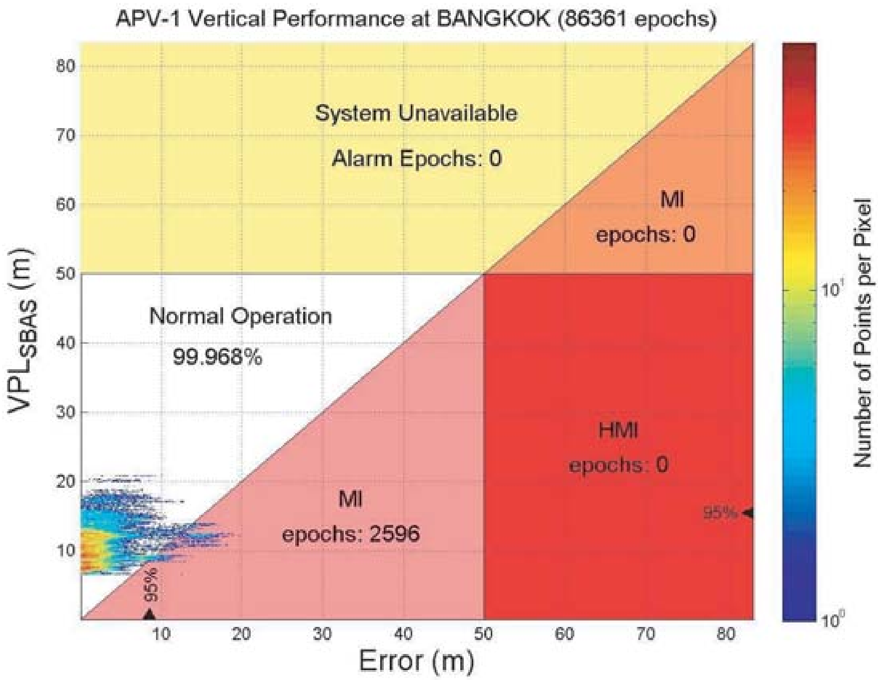

Figure 7. APV-I vertical performance.

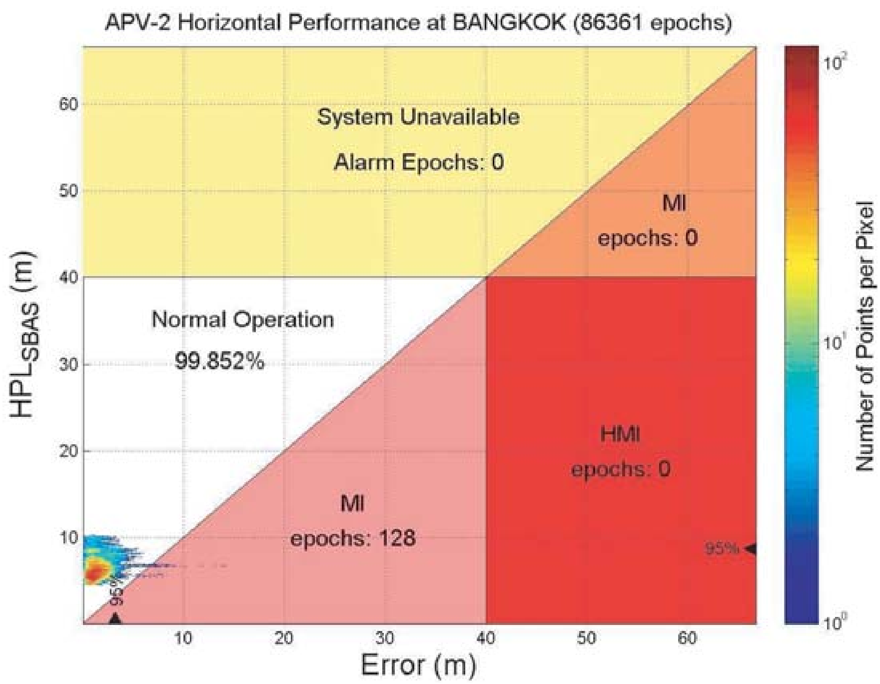

Figure 8. APV-II horizontal performance.

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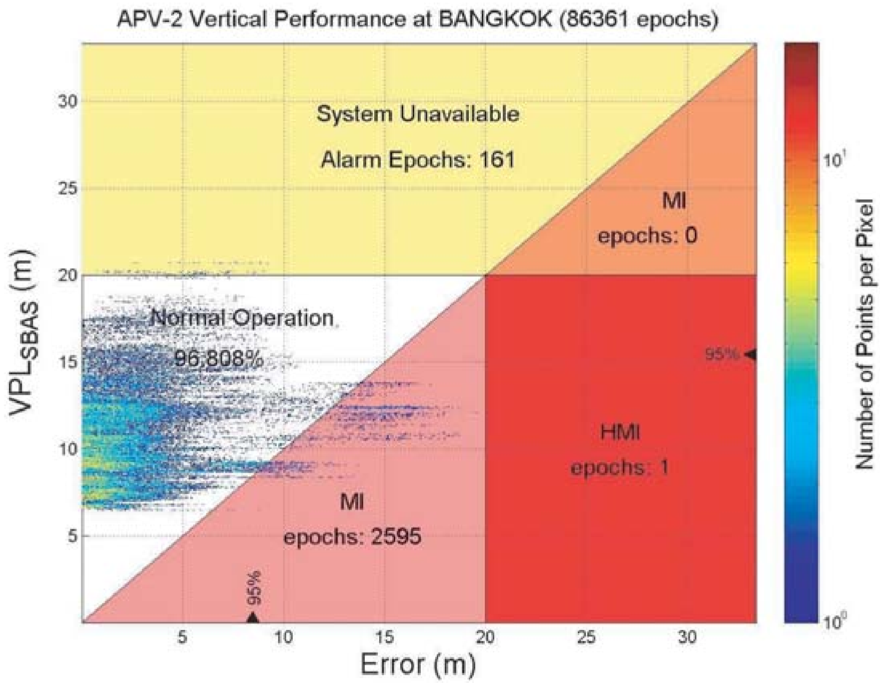

Figure 9. APV-II vertical performance.

Although these results satisfy the availability requirement for APV-II operation for horizontal navigation, they do not satisfy the requirement for vertical navigation. Moreover, in Figure 9, an epoch of hazardously misleading information (HMI) is observed. This HMI is not acceptable by the civil aviation community since it can lead to an unsafe navigation service for aircraft.

4. CONCLUSION AND DISCUSSION ON FUTURE WORKS. This paper describes the Asia-Pacific GNSS Test Bed system architecture and analyses the system performance using the initial data collected at the Bangkok site. The preliminary results of the SBAS performance through the implementation of the Test Bed indicate that accuracy requirements for APV-I and APV-II operations can be met by the test configuration. However, better integrity algorithms need to be studied and developed to reduce integrity failures and increase system's availability. Being a wide-area algorithm, SBAS is susceptible of local multipath signals. Further investigations on an impact of multipath on the system performance as well as algorithms to reduce multipath effects are suggested. Moreover, further studies on how well the SBAS algorithm can estimate ionospheric delay are recommended in order to improve the system's integrity performance.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support from the APEC GNSS Implementation Team, Aeronautical Radio of Thailand, and the United States Trade and Development

Agency. Special thanks are extended to colleagues at Chulalongkorn University and AEROTHAI GNSS Lab for their continuous contributions to the research project. This paper is based on the presentation made at the International Conference on Space Technology & Geo-Informatics 2006, Chonburi, Thailand, November 5th–8th.

REFERENCES

ICAO (2002) Annex 10 to the Convention on International Civil Aviation, Volume 1, Amendment 77 (SARPS). ICAO.

Pringvanich, N. and Abhakara, P. (2005a) Progress of the Asia-Pacific GNSS Test Bed. *Proceedings of 2005 ION NTM Conference*, Monterey, CA.

Pringvanich, N. and Abhakara, P. (2005b) GNSS Integrity and GNSS Augmentation Systems. *Proceedings of the National Conference on Mapping and Geo Informatics 2005*, Bangkok, Thailand.

Pringvanich, N., Kittisuwan, T. and Abhakara, P. (2005) Asia-Pacific GNSS Test Bed: A Stage for Regional Collaboration toward the Implementation of GNSS. *Proceedings of 2005 ATCA Conference*, Dallas/Fort Worth, TX.

RTCA (2001) Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment (WAAS MOPS), RTCA Document No. DO-229C, RTCA.