COMPARATIVE ANALYSIS OF THE ALGORITHMS FOR DETERMINATION OF THE EGNOS PERFORMANCE INDICATORS

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Abstract

Key words: Dilution of Precision, Safety Index, Protection Level, Position Error, Misleading Information

This report presents an investigation of the state of EGNOS Approach with Vertical Guidance. The EGNOS performance is evaluated and a comparison of the efficiency of EGNOS parameters determination algorithms is made. In this work the parameters of the EGNOS system (accuracy, integrity, availability and continuity) are experimentally evaluated using real data from EGNOS collected by EGNOS Monitoring Station for a period of one year.

Introduction

In this work a comparative analysis of the EGNOS performance indicators determination algorithms suggested in the literature [1] and [2] is presented. The main task of the experiments is to determine the xPL (Horizontal and Vertical Positional Levels) so that the error can exceed these levels with probability of less than 10^{-7} vertically and 10^{-9} horizontally.

In Bulgaria there are two Monitoring Stations that compile and analyze data for the needs of EDCN (Eurocontrol EGNOS Data Collection Network). One of them is placed at the Air Traffic Services Authority of Burgas, the other is placed at the Technical University of Sofia. In Sofia it operates with the Pegasus software version 4.6.0 and a Septentrio PolaRx2 reciever. [3] PEGASUS stands for Prototype EGNOS Analysis System Using SAPPHIRE and is a software package, which is an important means to control the characteristics of EGNOS. It includes the algorithms for analysis of the positioning characteristics, autonomous control of the integrity and availability of the GNSS signals. It evaluates HPL (Horizontal Protection Level) and VPL (Vertical Protection Level), which are the key to the integrity concept.

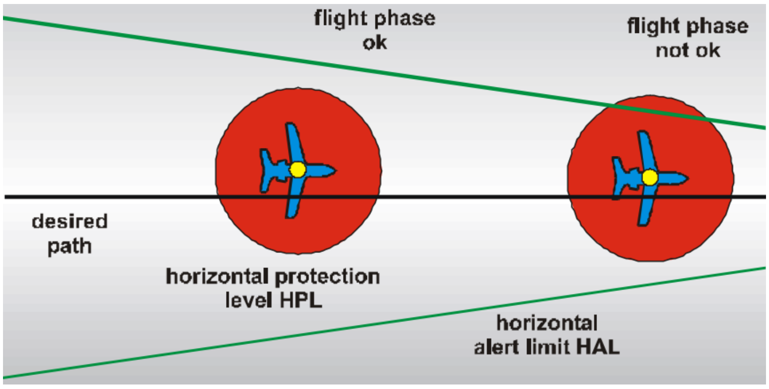

Fig. 1. Horizontal Protection Levels and Horizontal Alert Limit [2]

HPL is the radius of a circle in the horizontal plane, with the centre being at the true aircraft position, which describes the region which is assured to contain the indicated horizontal position. It is the horizontal region for which the missed alert requirements can be met. VPL is the half length of a segment on the vertical axis, with the centre being at the true aircraft position, which describes the region which is assured to contain the indicated vertical position. It is the vertical region for which the missed alert requirements can be met. [2]

HPL and VPL are calculated to protect users from potential deterioration of the system, which may result in HPE (Horizontal Position Error) and VPE (Vertical Position Error) exceeding certain levels called HAL (Horizontal Alert Limit) and VAL (Vertical Alert Limit) determined by ICAO, respectively. [4]

The basic system parameters must guarantee that the user is informed on his position with sufficient

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accuracy and is alerted on time when the system exceeds tolerance limits.

1. **Investigation of the state of EGNOS Approach with Vertical guidance for Europe provided by ESSP**

1.1. EGNOS APV-I Availability

It is defined as the percentage of epochs in a month/in the period in which the Protection Level is below Alert Limits for this APV-I service (HPL<40m and VPL<50m) over the total period.

Figures 2-4 present the EGNOS APV-I Availability data given by ESSP (European Satellite Services Provider) for the period April 2012 – March 2013 [6], for May [7] and December 2014 [8] for Europe, respectively. [5]

The availability of the system for APV-I for Sofia for the period April 2012 – March 2013 reaches 99.6%. The availability of the system for APV-I for Sofia on May 2014 reaches 99.9% and on December 2014 reaches 99.6%.

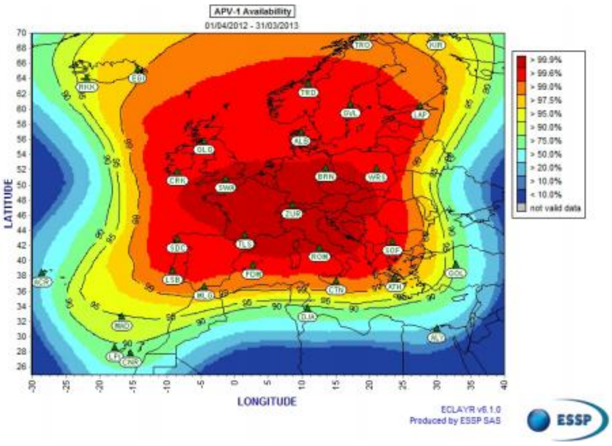

Fig. 2. EGNOS APV-I Availability, April 2012 – March 2013 [6]

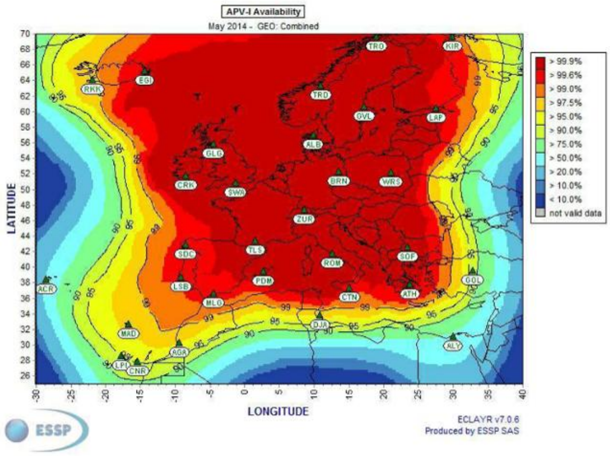

Fig. 3. EGNOS APV-I Availability, May 2014 [7]

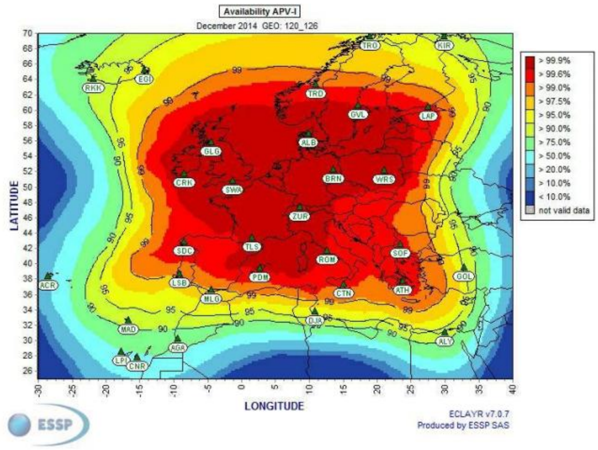

Fig. 4. EGNOS APV-I Availability, December 2014 [8]

1.2. EGNOS APV-I Continuity Risk

It is defined as the result of dividing the total number of single continuity events using a time-sliding window of 15 seconds by the number of samples with valid and available APV-I navigation solution. A single continuity event occurs if the system is available at the start of the operation and in at least one of the following 15 seconds the system becomes unavailable.

Figures 5-7 present the EGNOS APV-I Continuity for the period April 2012 – March 2013 [6], for May [7] and December 2014 [8] for Europe, respectively. [5]

APV-I continuity between April 1st 2012 and March 31st 2013 is reported as the number of single continuity events in a time-sliding window of 15 seconds over the total number of available samples in the period. The result is presented as the probability per 15 seconds of occurrence of one discontinuity event.

The continuity of the system for APV-I for Sofia for the period April 2012 – March 2013 is about $2.5x10^{-4}$. The continuity of the system for APV-I for Sofia on May 2014 is about 10^{-4} and on December is about $5x10^{-4}$.

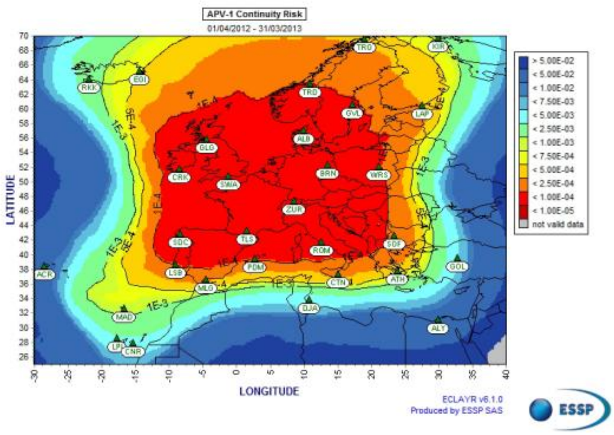

Fig. 5. EGNOS APV-I Continuity Risk, April 2012 – March 2013 [6]

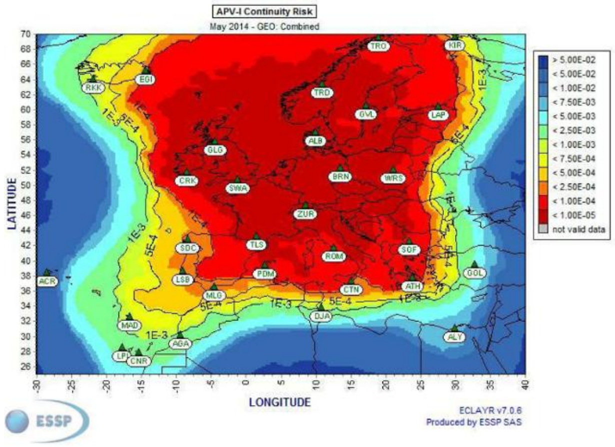

Fig. 6. EGNOS APV-I Continuity Risk, May 2014 [7]

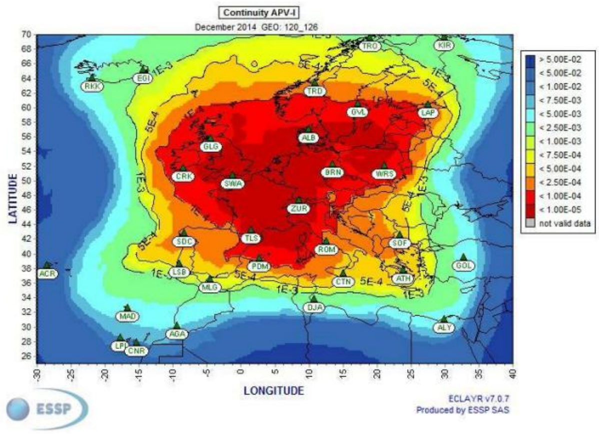

Fig. 7. EGNOS APV-I Continuity Risk, December 2014 [8]

1.3. EGNOS APV-I Integrity Event

It is defined as an event when the Navigation SE (System Error) is greater than or equal to the corresponding PL (Protection Level) for APV-I.

No integrity event has been identified for any receiver of the monitoring network for the period April 2012 – March 2013 [6], for May 2014 [7] and for December 2014 [8].

Figures 8 and 9 provide the histogram for HSI (Horizontal Safety Index) and VSI (Vertical Safety Index) corresponding to the RIMS sites located inside the APV-I for the period April 2012 – March 2013 for Europe. [5] [6]

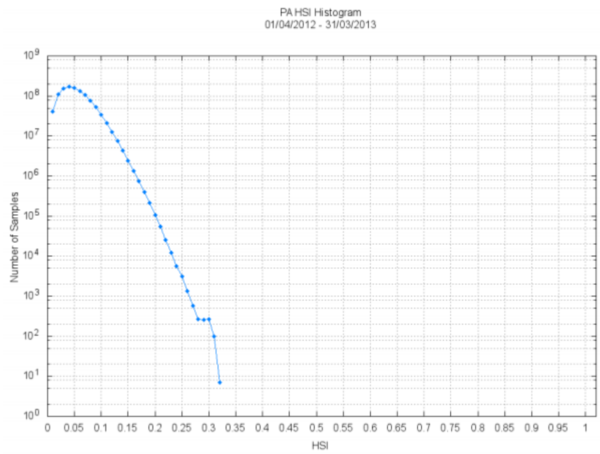

Fig. 8. EGNOS APV-I Horizontal Safety Index, April 2012 – March 2013 [6]

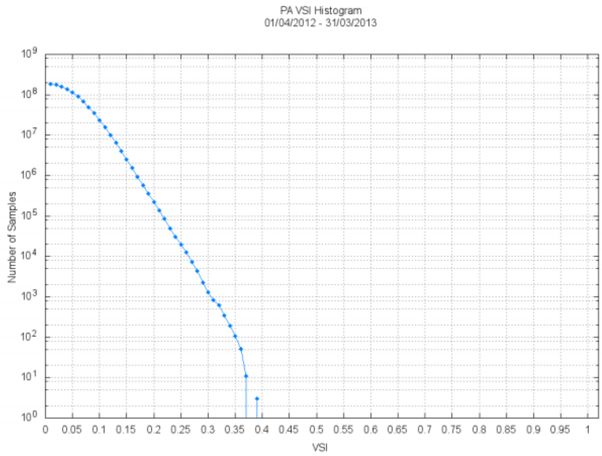

Fig. 9. EGNOS APV-I Vertical Safety Index, April 2012 – March 2013 [6]

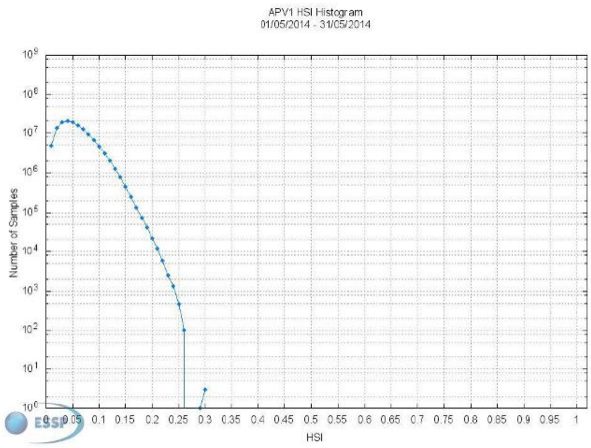

Fig. 10. EGNOS APV-I Horizontal Safety Index, May 2014 [7]

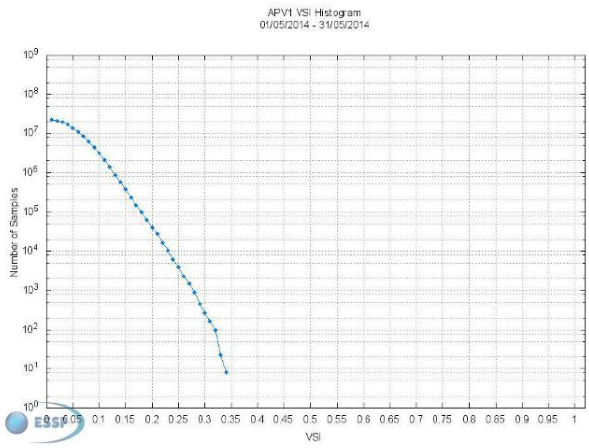

Fig. 11. EGNOS APV-I Vertical Safety Index, May 2014 [7]

Safety Index is defined as the relation between Navigation System Error and Protection Level (assuming PA algorithms to compute xNSE and xPL) for each second. An xPE/xPL ratio greater than 1 indicates that a Misleading Information situation has occurred.

The Horizontal and Vertical Safety Indexes remain below 0.4 for all stations throughout the whole period, which represent a very good integrity margin.

Figures 10 and 11 provide the histogram for HSI and VSI for each second when accumulating measurements from the different EGNOS stations of Europe for May 2014. [5] [7]

HSI and VSI are <0.75 so there is no potential possibility for Misleading Information. These histograms prove that the Protection Level is below the APV-I Alarm Limit.

Figures 12 and 13 provide the histogram for HSI and VSI for each second when accumulating measurements from the different EGNOS stations in Europe for December 2014. [5] [8]

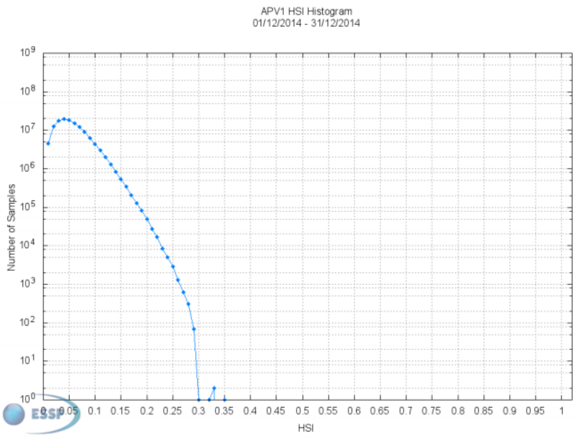

Fig. 12. EGNOS APV-I Horizontal Safety Index, December 2014 [8]

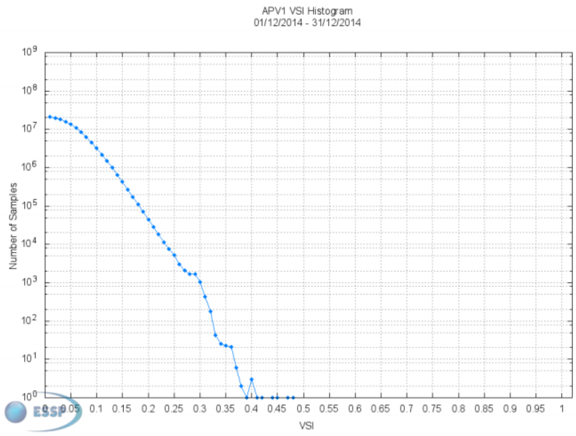

Fig. 13. EGNOS APV-I Vertical Safety Index, December 2014 [8]

HSI and VSI are <0.75 so there is no potential possibility for Misleading Information. These histograms have considered that Protection Level is below APV-I Alarm Limit.

1.4. EGNOS APV-I Accuracy

It is reported as the 95th percentile of the Horizontal and Vertical Navigation System Error over the month, at the monitored sites when the APV-I service is available (HPL<40m and VPL<50m).

The APV-I accuracy values in meters for all stations in Europe for the period April 2012 – March 2013 [6]: HNSE 95% – 1.3 m, VNSE 95% – 2.3m. The APV-I accuracy values in meters for Sofia (for example) station for May 2014 [7]: HNSE 95% – 1.2 m, VNSE 95% – 2.4m, 99.97% of samples with APV-I service available. The APV-I accuracy values in meters for Sofia (for example) station for December 2014 [8]: HNSE 95% – 1.1 m, VNSE 95% – 2.1m, 99.71% of samples with APV-I service available. [5]

These results represent a very good level of accuracy for Europe.

2. System availability at Delft University of Technology, Eurocontrol Experimental Centre, Pansa Warsaw and Technical University of Sofia for APV-I, APV-II and CAT-I for the period of one year, determined by Pegasus software [2] [9] [10] [11] [12]

Table 1

	APV-I	APV-II	CAT-I
Delft University of Technology	99.261%	98.202	46.848
Eurocontrol Experimental Centre	99.702	98.589	27.566
Pansa Warsaw	98.897	95.889	25.718
Technical University of Sofia	98.816	85.026	5.610

Table 1 represents the comparison of the system availability at Delft University of Technology, Eurocontrol Experimental Centre, Pansa Warsaw and Technical University of Sofia for APV-I, APV-II and CAT-I for the period of one year.

The values of the availability for APV-I, APV-II and CAT-I for the Technical University of Sofia, calculated according to the Pegasus software (PS) algorithm, are remarkably lower than those for the Delft University of Technology, Eurocontrol Experimental Centre and PANSA Warsaw. This demonstrates the need for a significant improvement of the availability of the system.

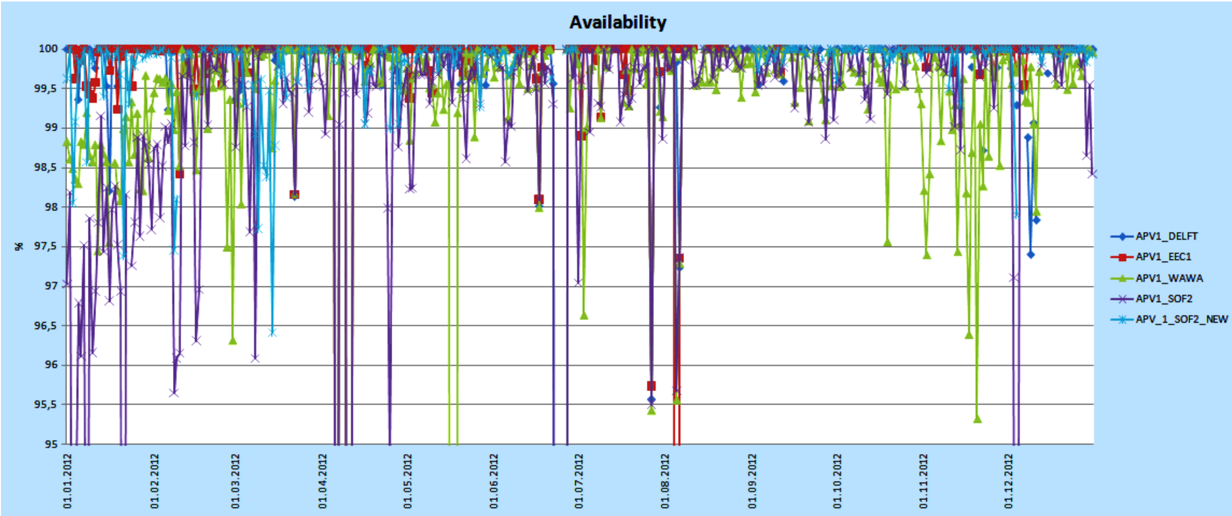

Fig. 14. Comparative diagrams of availabilities for APV-I

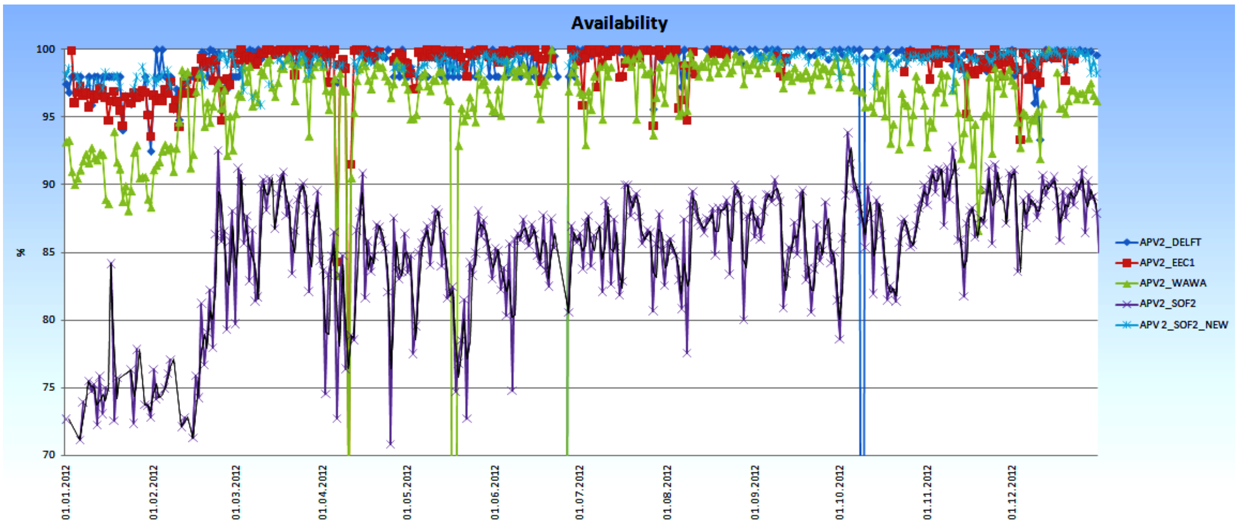

Fig. 15. Comparative diagrams of availabilities for APV-II

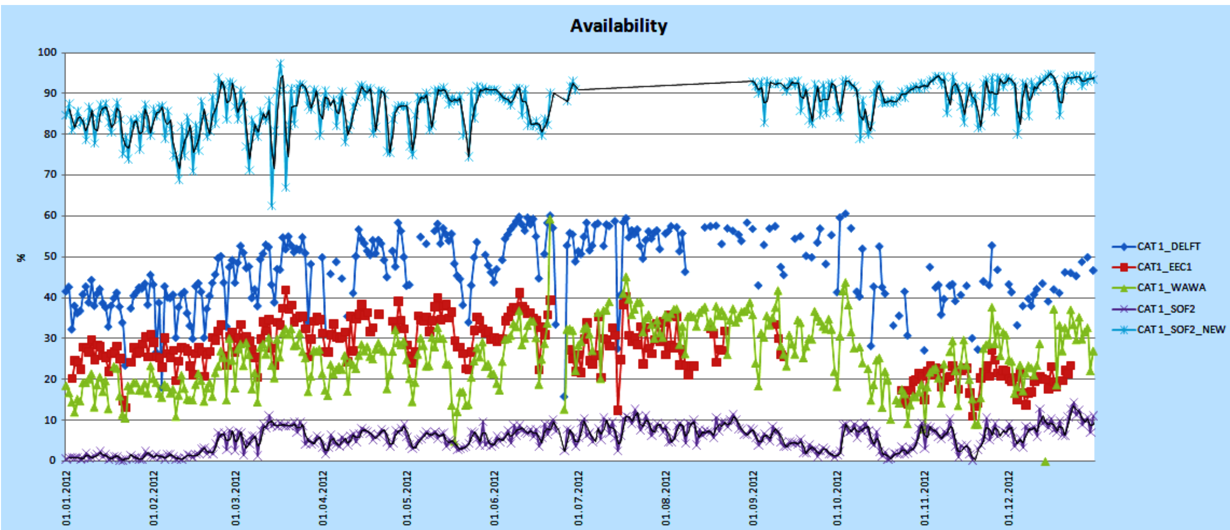

Fig. 16. Comparative diagrams of availabilities for CAT-I

Comparative diagrams of the availability of the EGNOS system for APV-I (Approach Procedure with Vertical Guidance), APV-II and CAT-I (Precision Approach Flight Phase Category I) for the period of one year are presented on figures 14-16. The data is taken from the daily reports of Delft University of Technology (DELFT – The Netherlands), Eurocontrol Experimental Centre (Bretigny – France), PANSA Warsaw (Warszawa – Poland) and Technical University of Sofia (SOF2 – Bulgaria), in rates.

3. Comparison of the values calculated according to Pegasus software [2] and Error Extraction algorithm [1] for Technical University of Sofia for the period of one year

A comparison of Maximum Horizontal Safety Index values calculated according to PS (Pegasus software) and EEA (Error Extraction Algorithm) for Technical University of Sofia in the period from 01.01.2012 to 31.12.2012 is presented on figure 17. The graph shows that the SI (Safety Index) is not greater than the limit of 0.75. Accordingly, there is no potentially misleading information.

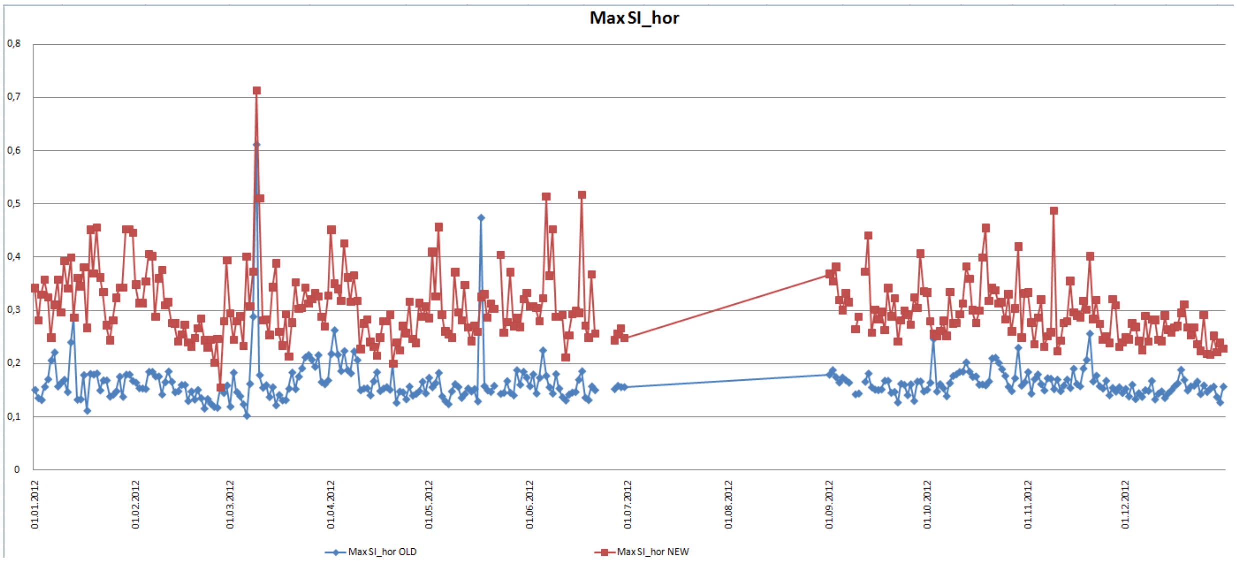

Fig. 17. Comparative diagrams for Maximum Horizontal Safety Index

A comparison of Maximum Vertical Safety Index values calculated by PS and EEA for Technical University of Sofia in the period from 01.01.2012 to 31.12.2012 is presented on figure 18. On the graph a high peak is observed. Safety Index is greater than the limit of 0.75. Accordingly, there is a potentially Misleading Information. The Safety index is less than 1, which makes no anomalous situation (Hazardously Misleading Information).

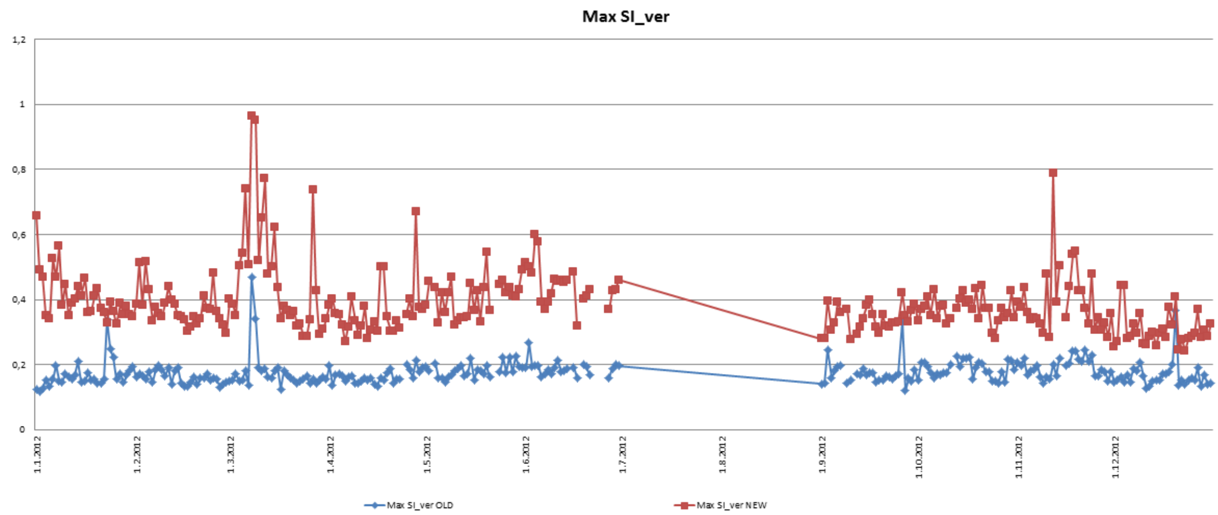

Fig. 18. Comparative diagrams for Maximum Vertical Safety Index

After a detailed examination of the graph, it is indicated that the Misleading Information is present on the dates 08.03.2012 and 09.03.2012. An analysis of EGNOS work is made with the signal of PRN 120 for the dates 08.03.2012 and 09.03. 2012. The navigation data is processed with PEGASUS and MatLab software products. After processing the navigation data, it is concluded that bad satellite geometry is the reason for the deterioration of the system accuracy.

A comparison of values for APV-I , APV-II, CAT-I and for Probabilities of discontinuity calculated by PS and EEA for Technical University of Sofia in the period from 01.01.2012 to 31.12.2012 is presented on figures 21-24.

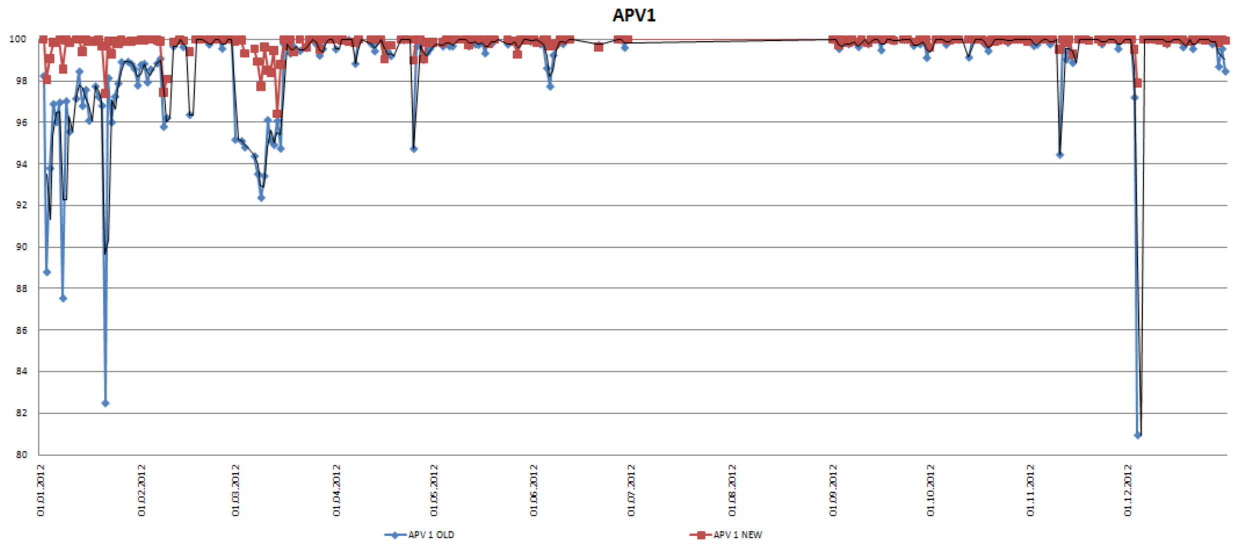

Fig. 21. Comparative diagrams for Approach Procedure with Vertical Guidance I

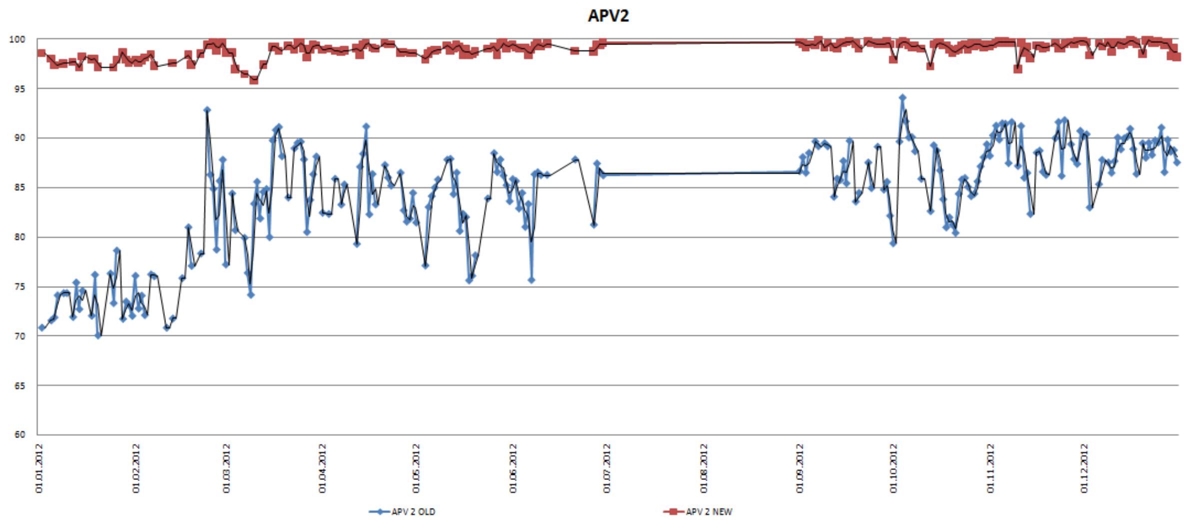

Fig. 22. Comparative diagrams for Approach Procedure with Vertical Guidance II

Table 2

	Pegasus software	**Error Extraction Algorithm**
Max SI (hor) Maximum Horizontal Safety Index	0.165	0.303
Max SI (ver) Maximum Vertical Safety Index	0.175	0.391
APV-I Approach Procedure with Vertical Guidance I	98.816	99.809
APV-II Approach Procedure with Vertical Guidance II	85.026	99.018
CAT-I Precision Approach Flight Phase Category I	5.610	88.431
P (disc.) Probabilities of discontinuity	0.129	0.148

Table 2 presents a comparison of the values *for Max SI (hor), Max SI (ver), APV-I, APV-II, CAT-I and P (disc.),*calculated by Pegasus software and Error Extraction Algorithm for the TU-Sofia for the period of one year.

The values of the availability for APV-I, APV-II and CAT-I, calculated according to Pegasus software, are 98.816%, 85.026% and 5.61%, respectively. The same values of the availability for APV-I, APV-II and CAT-I, calculated according to Error Extraction Algorithm are, as follows: 99.809%, 99.018% and 88.431%. These values indicate a significant improvement of the availability of the system.

It should be noted that the availability of the APV-I, calculated according to EEA, is more than the required 99% and approximates to 100% accuracy of the system.

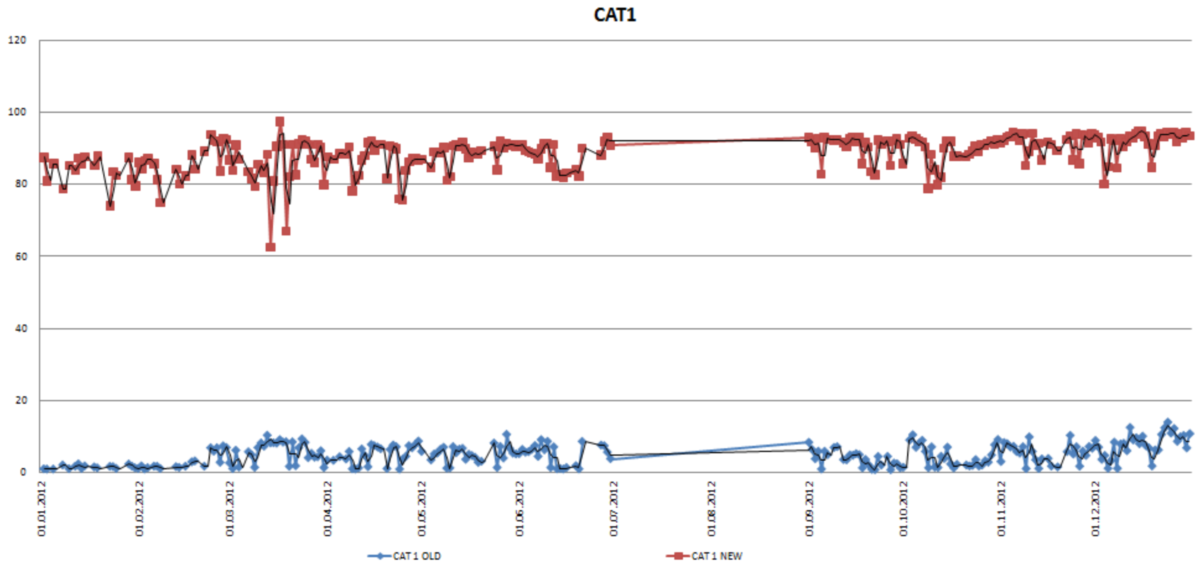

Fig. 23. Comparative diagrams for Precision Approach Flight Phase Category I

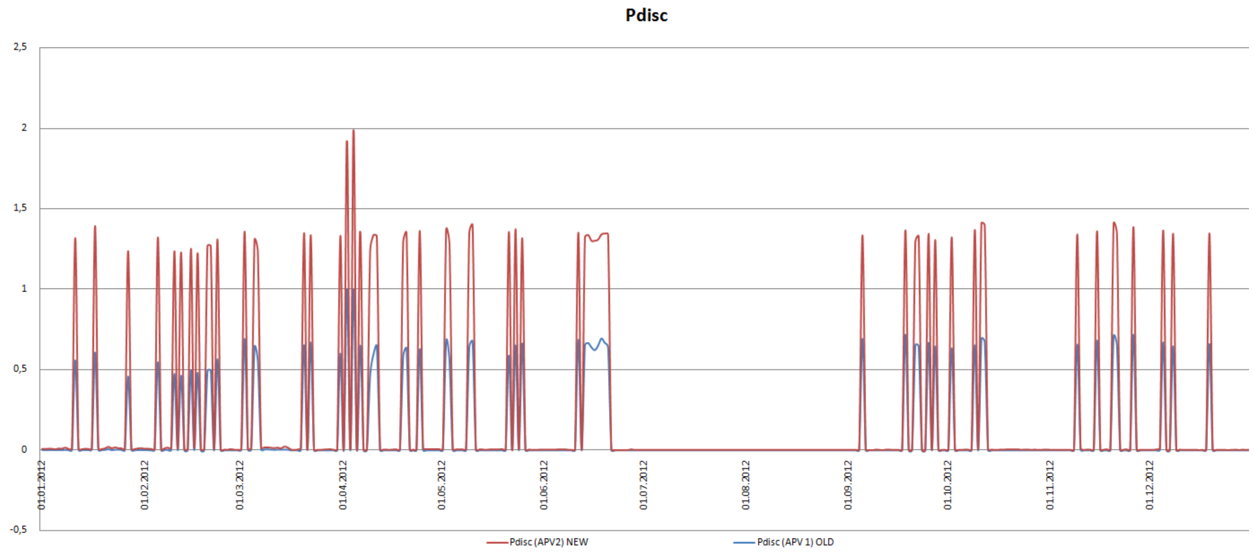

Fig. 24. Comparative diagrams for Probabilities of discontinuity

Conclusion

The existing global satellite positioning systems do not provide the required accuracy, availability, integrity and continuity. With the launch of the European wide-area differential correction system EGNOS, the conditions for the implementation of the GPS technologies have improved significantly.

The availability of EGNOS to aviation means that aircrafts will be able to use satellite technologies to establish their vertical positioning during approaches. The established results support the claim: today, the EGNOS performance is stable and with high accuracy and integrity.

The conducted experiments confirm that the designed new algorithms based on the Error Extraction Algorithm described in literature [1] are very promising. They allow reduction of the standard deviation of the error and significantly improve the availability of the European Geostationary Navigation Overlay Service for Bulgaria.

It should be noted that experiments are an important element of any system. A lot of similar experiments should be conducted because they are of great importance as additional tools in system performance assessment.

Acknowledgement

The authors would like to express their gratitude to the Technical University of Sofia, Faculty of Transport, Department of Aeronautics for the financial support with publishing the paper.

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