Modelling of Performance Key Identifiers for Characterisation of Current Capabilities on Maritime Augmentation Services

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Abstract

Currently used maritime augmentation services (IALA Beacon DGNSS and DGNSS via AIS) are designed and operated to fulfil the accuracy and integrity requirements on positioning needed for ship's navigation in coastal areas. In the frame of e-navigation strategy the maritime community has identified the reliable and resilient PNT data provision as user need. Reliability characterises the ability of a system to perform their specified functions according nominal conditions during a certain period of time. Resilience is the ability of a system to detect and compensate external and internal disturbances, malfunction and breakdowns in parts of the system. This should be achieved without loss of functionalities and preferably without degradation of their performance. For both, reliability and resilience, the implementation of appropriate integrity monitoring functions is necessary. The paper discusses the four data processing layers of a maritime GNSS augmentation services regarding feasibility and effectiveness of integrity monitoring methods, whereby special attention is laid on usable Performance Key Identifiers and their modelling.

1. Introduction

The reliable and resilient provision of navigational data has been arisen to an important aim of the further enhancement of the maritime traffic system. Performance and global availability are the main reasons that GNSS has evolved to a core component ensuring the world-wide PVT data provision for ship's navigation. However, the vulnerability of GNSS against a variety of signal disturbances (e.g. interferences, jamming, spoofing) reinforce the need for GNSS augmentations services (DGNSS, SBAS) as well as alternative radio-navigation services (eLoran, R-Mode).

GNSS augmentation services provide augmentation data to enable that users can achieve higher performance levels in determining PVT data. Furthermore they are an appropriate mean for the independent assessment of the current GNSS system capability and signal performance. Recent developments have shown that augmentation services designed for safety-critical applications should satisfy two fundamental characteristics:

- Firstly, the system should be able to perform all required functions needed for the provision of specified augmentation data. A reliable provision of augmentation data can be expected, if the service is able to perform all functions according the specified conditions during a certain period of time.
- Secondly, the monitoring and indication of data and system integrity can only be realized, if appropriate monitoring techniques can be applied to enable the detection of error sources and to evaluate the performance of service components including augmentation data provision in real time.

For each kind of integrity monitoring it is necessary to dispose of realistic models (system, measurement) and appropriate performance key identifiers (PKI). Aim of these PKI's is on the one hand the comprehensive characterisation of nominal system operation or characteristics of measurements and included errors. On the other hand PKI's should enable that occurring threats can be detected in real time especially for safety-critical applications.

At begin a generalized model of maritime augmentation systems will be introduced to explain what and where PKI's could be used. For selected PKI's a task-orientated evaluation of their relevance for error detection and performance evaluation will be investigated and discussed. For this purpose our Maritime Ground Based Augmentation System (MGBAS) in the Research Port Rostock has been used. The MGBAS has been deployed in former projects by the German Aerospace Centre (DLR) to demonstrate that ships can determine their positions with accuracies better than 1 dm. Since then our developments are focussed on the improvement of integrity monitoring techniques evaluating the performance of used GNSS and provided augmentation service.

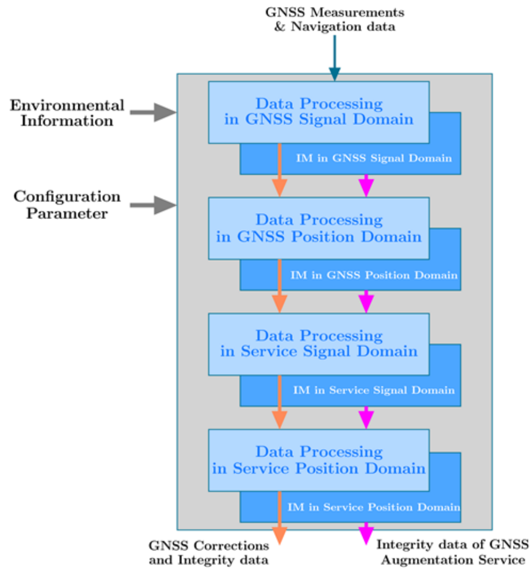

Figure 1: Generalised Data Processing within the GNSS Augmentation Service

2. SERVICE MODEL and PERFORMANCE KEY IDENTIFIERS

2.1 Service Model

During the review of "IALA's Recommendation on the Performance and Monitoring of a DGNSS Service in the frequency band 283.5 - 325 kHz" a generalized model of maritime GNSS augmentation services has been pointed out (Figure 1).

In principle, the service provision is realized by 4 sub-facilities representing the data processing in GNSS signal domain, GNSS position domain, DGNSS signal domain, and DGNSS position domain. Each of the processing layers could be equipped with integrity monitoring functions contributing to the integrity evaluation of used GNSS, provided DGNSS service and expected positioning performance at user site.

2.2 Scope of Integrity Monitoring

Objective for integrity monitoring in safety-critical services is the real time indication of data and system integrity regarding applied infrastructures (e.g. used GNSS and signals), used sensors (e.g. GNSS receivers) and provided data products (e.g. correction data and integrity information). From a maritime user's point of view integrity monitoring should provide the information, whether used systems and services fulfil performance requirements to enable a safe realisation of nautical tasks. Therefore integrity monitoring should be addressed to a specific set of requirements on system functionalities, data quantity and quality.

In minimum the developed integrity monitoring algorithms evaluate the occurrence of events having the potential to cause hazardously misleading operations decreasing the performance of service provision and utilization. Within the navigation context, the focus is laid on bounding of navigational errors. Often a direct evaluation of requirements like positioning accuracy is impossible at user site. Therefore sufficient performance key indicators (PKI) should be identified to enable an effective integrity monitoring of used GNSS and provided augmentation services in relation to specified requirements. In the case of augmentation services the integrity monitoring should be related to:

- The feasibility of service provision: evaluating, if GNSS signals available at sensor and monitoring stations are sufficient to enable the provision of GNSS augmentation data;
- The quality of service provision: self-evaluation of provided augmentation data covering e.g. correction data and integrity information in the case of code-based DGNSS or reference measurements and integrity information in the case of phase-based DGNSS;
- The indication of usability of provided service in the application context: performance evaluation or estimation taking into account application conditions and dependencies e.g. coverage area, decorrelation aspects and additional error sources.

2.3 PKI’s per Functional Service Layer

Integrity monitoring of GNSS augmentation services can be done alternative or complementary on 2 ways: on system level as well as user level.

An indirect proof of performance on system level is given, if an artificial user applies the provided augmentation data and is thus in a position to determine the PVT data with the required performance. Often, this methodology of integrity monitoring is wrongly equated with achievable integrity at user site. However, differences in local reception conditions and error decorrelation effects are reasons that the performance of positioning at artificial and real users will be different. Integrity monitoring on system level deals with the detection and evaluation of single error sources and continuative their indication and/or exclusion of further processing. This serves an improved service provision. Furthermore, if residual errors are determined they could be used for a parametrized error modelling and ultimately for the estimation of protection levels at user site. Integrity monitoring functions and potential PKI’s will be explained per service layer and discussed in relation to their tasks and expected information.

1. Integrity monitoring in the ***GNSS signal domain*** evaluates the usability of individual GNSS signals for service provision and/or GNSS based positioning. Usability will be given, if the satellite-specific code and carrier phase measurements as well as assigned navigation data are completely provided with the required quality. Applicable performance key indicators in this domain are amongst others range errors, code and phase noise, carrier-to-noise ratio (CNR) (or signal-to-noise ratio (SNR)), frequency of cycle slips, ionospheric path delays and gradients. For potential PKI’s it is necessary to model and describe their nominal behaviour taking into account dependencies such as daily, weekly and seasonal variations, atmospheric conditions, and site- and equipment-specific characteristics. Due to the limited redundancy in measurements per GNSS satellite the integrity monitoring will primary be realized by plausibility and consistency tests. Therefore PKI’s are used to differ between nominal and significant disturbed observations per GNSS satellite for the detection of system anomalies and outliers.

2. Integrity monitoring in the ***GNSS position domain*** evaluates the feasibility of GNSS based positioning (e.g. number of usable satellites, dilution of position) and the performance of positioning (e.g. availability of position and current position error). Therefore integrity monitoring in the GNSS signal domain can evaluate and improve the integrity monitoring results of the GNSS signal domain by joint assessment of all available GNSS observations and information. Valid indicators in this domain are the Dilution of Precision; the number of available (and excluded) satellites, as well as the current accuracy of GNSS based positioning. A further task of integrity monitoring in this domain could be the proof of applicability and effectiveness of various RAIM techniques. Hereby the dependencies of RAIM on the variety of positioning techniques and search strategies should be considered.

Performance indicators of the GNSS signal and position domain create the basis to decide whether the provision of GNSS augmentation signals is feasible or not. In comparison, the data processing in the service signal and position domain focuses more on the evaluation of provided service regarding its benefit for GNSS/DGNSS-based positioning.

3. Integrity monitoring in the ***DGNSS signal domain*** serves the evaluation, if provided augmentation and correction data are valid and their application improves the range measurements to individual GNSS satellites. For this purpose plausibility and consistency tests are applied on measurements at IMS corrected with augmentation data determined at RS and intended for service provision. For potential PKI's it is also here necessary to model and describe their nominal behaviour taking into account temporal or site- and equipment-specific characteristics. In the absence of additional information, PKI's applicable e.g. for code-based DGNSS in this domain are the Pseudorange Residual (PRR) and the User Differential Range Error. If estimates of decorrelation effects such as the age of corrections terms are appropriate to appear as additional PKI's can only be answered in relation to specific DGNSS techniques taking into account site specific characteristics, if necessary.
4. The feasibility of DGNSS based positioning (e.g. number of corrected satellite signals, resulting dilution of position) and the performance of DGNSS-based positioning (e.g. availability of position and current position error) are potential PKI's for integrity monitoring in the ***DGNSS position domain***. Aim of the monitoring is the indirect proof of service performance on system level. Hereby the IMS acts as an artificial user to demonstrate the usability of the GNSS augmentation service for positioning.

Furthermore a long-term evaluation of PKI's in the DGNSS signal and service domain is essential to characterize the operational performance of DGNSS service provision in terms of reliability and proofed resilience against individual error sources.

3. EXPERIMENTAL ANALYSES AND RESULTS

3.1 Experimental System

To perform the monitoring of used GNSS, applied services and provided augmentation data, an IALA Beacon DGNSS concept of integrity monitoring is implemented, where the analysis in each of the four domains described in section 2.3 is implemented and validated. For the scope of this progress work, the developed shore-side system is constrained to single constellation GPS based service provision. The IALA Beacon DGNSS architecture (Figure 2) serves two fundamental purposes:

1. The provision of differential GPS code corrections, computed at the reference station (RS), to account errors on the observations originated by the ionosphere as well as satellite clock and ephemerides errors and improve the accuracy of users. The reference station is realised within this work by the corrections transmitted by the station Groß-Mohrdorf, in the state Mecklenburg-Vorpommern in the north of Germany, which are valid for the Baltic Sea.

2. The monitoring of the performance of the corrections, at the integrity monitoring station (IMS), to evaluate whether the application of these corrections contributes to meet the requirements of navigational applications. Main task of the IMS is the validation of the applicability of these corrections in relation to de-correlation effects caused by the different GNSS availability conditions at the IMS site. DLR's Integrity Monitoring Station -msr03- is located in Rostock (Germany), where a considerably large amount of daily maritime traffic defines it as a suitable environment for the testing and validation of such a system. msr03 is constituted by a continuously operating reference station, recording GPS data in a time rate of 20Hz.

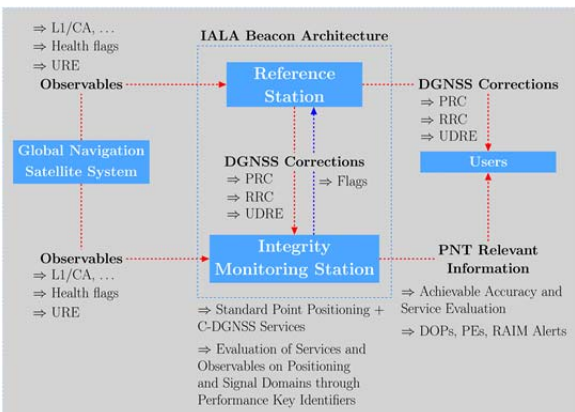

Figure 2: Simplified IALA Beacon DGNSS concept within the MGBAS

All the relevant sensor measurements comprise the GPS week 1836, between the 15th and the 21st of March (days of year -doy- 74 to 80). Since the available GNSS constellation for the two consecutive days is expected to be (near) similar, changes on the behaviour of the proposed parameters are investigated with the purpose to detect errors on the observations associated to malfunctions on the system or to natural phenomena disturbing the data and diminishing the accuracy of the data.

The evaluation of the performance of the implemented system is evaluated using DLR's Real-Time software Framework (RTFramework) implemented in C++ [Gewies et al. (2012)]. Following, the description of the numerical findings for each domain and service.

3.2 GNSS Signal Domain

It is well-known, that GNSS signals tracked at low elevations dispose of reduced Carrier-to-Noise Ratio (CNR) and result into GNSS observables with decreased data quality. Previous investigations [Noack et al. (2009)] have shown that improved outlier detection can only be achieved, if the nominal behaviour of systematic and stochastic error sources will be modelled dynamically. Thus, the relation between CNR and elevation angle should be analysed to clarify if an unambiguous dependency exists or not. In relation to individual error parts it should be evaluated, if a dynamic modelling of error behaviour is necessary and if yes, what dependencies should be taken into account for modelling.

Previous investigations have shown [Noack et al. (2009)] that potential error sources can be described as function of Carrier-to-noise ratio (CNR). CNR plays also a central role into the implemented RAIM-FDE algorithm within our MGBAS. Figures **Error! Reference source not found.** show the relation between CNR and elevation angles determined at the site msr03 for days 16th and 17th of March (doy 75 and 76), respectively.

Satellites with low elevation angles exhibit lower values of CNR while those close to the zenith display the highest values, a result consistent with the influence of the path of the signal through the atmosphere on the power of the signal and the free-space path loss [Misra and Enge (2012)]. A defined trend is also observed at both sets of data, with most of the observation converging around the theoretical expected value of 40.94dB. However, data of doy 76 (Figure 3) are more densely accumulated toward values greater than 40.94dB, with different local maxima of accumulated observations around (25°: 42dB) and (55°: 50dB), suggesting a difference regarding the quality of the second set of data, that could influence the positioning process. Mean behaviour as well as intra-variation of the CNR with respect to the elevations angle, display similar behaviour for both days (Figures 3), with maximum standard deviations of 2.0dB and 2.25dB, respectively.

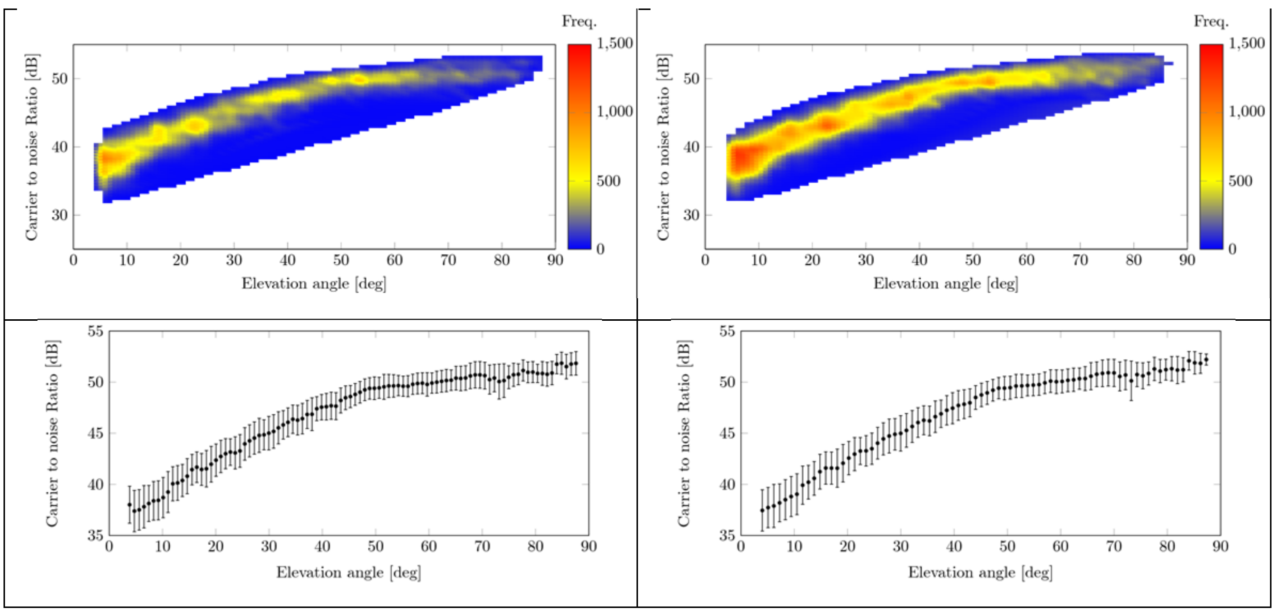

Figure 4: Dependency between CNR and elevation angle at DoY 75 (left) and 76 (right) of year 2015 (upper figures: histogram; lower figures: 1σ value range around mean value)

GNSS observables in the signal domain can be further evaluated by estimating code as well as phase noise. Code noise can be determined by filtering of range measurements. Thus, a short term history of the incoming data is used to model the dynamic behaviour and to predict the next measurement. The difference between predicted and observed values is regarded as noise, when the filtering process takes few seconds, as in high-rate data streams Noack et al. (2009). A filtering of high-rate data enables short acquisition and reacquisition delays, before assessed code observations are provided again. Carrier smoothing is the preferred filtering technique to reduce the influence of multipath propagation on code phase measurements. Therefore, time constants of more than 1min. are necessary to achieve a separation between geometric conditioned code phase dynamic and multipath effects. A side effect of this filtering technique is the possibility to estimate the amount of multipath influences as a further quality parameter [Noack et al. (2009)].

Figures 4 show the behaviour of the code noise in relation with the elevation angle. Noise is mainly concentrated at lower elevation angles for the two sets of data, but data corresponding to doy 76 shows a large number of noise observations gathered around 20°, 40° and 55°. Noisier observations are expected to decrease the accuracy on the positioning process. However, the overall distribution of this variable display similar behaviour for both analysed days, with similar values for the mean and maximum intra-variations of 3m and 3.25m.

As both days count with the (nearly) the same available data, in account to the fact that the GNSS constellation repeated every 24 h , these small intra-variations on the behaviour of the PKI for both days is an indication that a natural phenomenon, in this case the activity of the ionosphere, influenced the collected data. How much is the influence of these phenomena for the positioning process, and determine whether it poses a threat for the navigation process, require the analysis in the following domains.

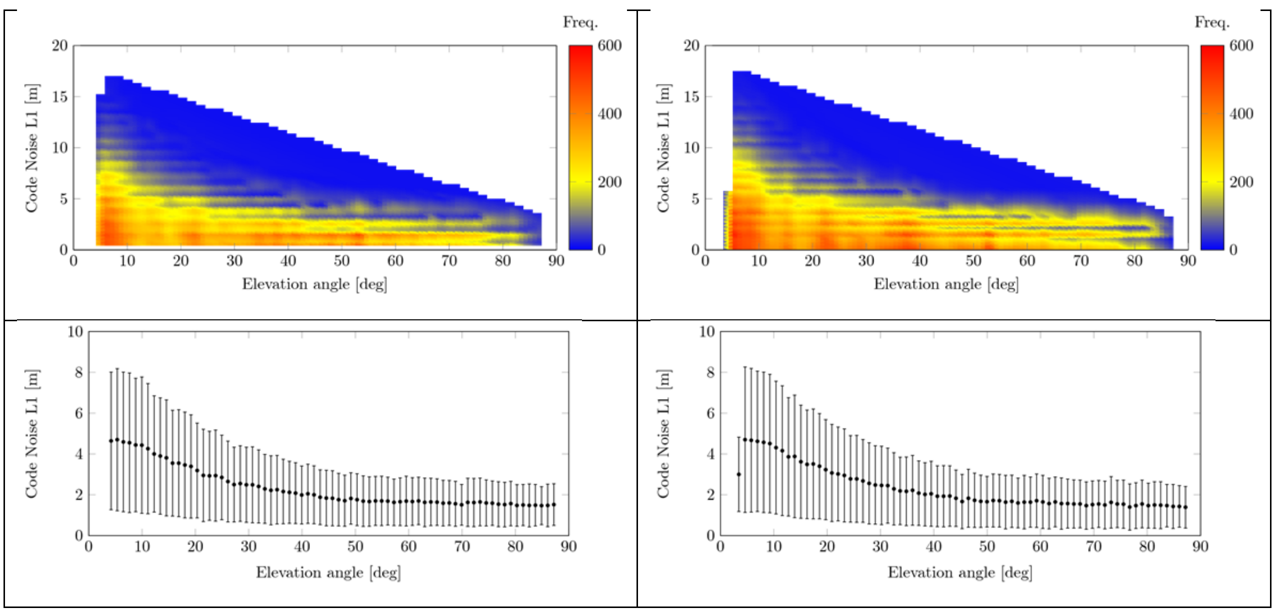

Figure 5: Dependency between code noise and elevation angle at DoY 75 (left) and 76 (right) of year 2015 (upper figures: histogram; lower figures: 1σ value range around mean value)

3.3 GNSS Positioning Domain

It is known that a poor geometry constellation and/or a low availability of satellites lead to an increased error on the final position solution. Moreover, site specific conditions, such as obstacles or effects affecting the individual links to the satellites (as described in the previous domain) may decrease the signal availability impairing the Dilution Of Precision (DOP) and ultimately the performance of positioning. DOP values are considered as measures to describe the influence of constellation geometry (available and visible satellites) on positioning and timing. Different DOP designations are available, e.g. HDOP for horizontal positioning or TDOP for timing. Epochs with a HDOP smaller than 7.5 are considered appropriated for position determination [Seeber (2003)]. The suitability of DOP to appear as performance indicator for positioning requires that the dependencies between both should be modelled.

Figures **Error! Reference source not found.** show the behaviour of the HDOP for the aforementioned days at the IMS. An additional parameter, the number of used satellites, is also displayed. Values for the two data sets show fairly good values, as they account the excellent visibility conditions for the reception of GNSS signals at the site. Values of the PKI during the observed epochs are below the suggested safe threshold with only few and small changes due to sudden variations in the number of satellites used for positioning. This similarity between the two sets of data is an expected result given the fact that the available GNSS constellation and geometry should be nearly the same for two consecutive days, if no changes of satellite constellation occurred.

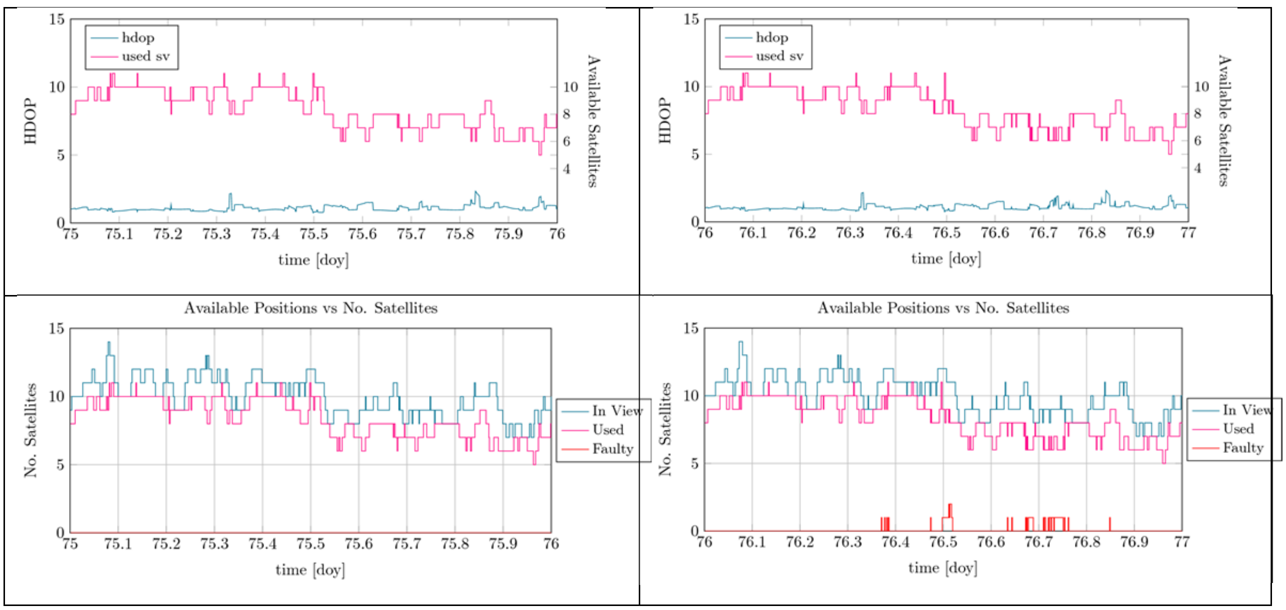

Figure 6: HDOP and number of satellites (in view, used and faulty) as time series at DoY 75 (left) and 76 (right) of year 2015 (upper figures: HDOP and used satellites for positioning; lower figures: satellite availability and exclusion of faulty satellites by RAIM-FDE)

Normally, Receiver Autonomous Integrity Monitoring (RAIM) Fault Detection and Exclusion (FDE) algorithms are applied at user site to detect significant errors and to exclude them from further data processing e.g. positioning. The implemented RAIM-FDE technique involves the use of a global test, to verify the consistency of the measurements, and a local test, to identify and down-weight the measurement blunders. The correspondent weights of the measurement blunders detected by the local test are reduced. The variance of the suspected measurement is exponentially increased (and consequently the weight is decreased) with an iteratively re-weighted least squares algorithm used to achieve consistency between the measurements by modifying the a priori measurement weights, obtained from a CNR variance model for pseudorange observation [Lanca et al. (2014)]. Thus, it is necessary to evaluate whether the results of the exclusion process can be considered as an indicator of the usability of the satellite and how the exclusion of particular satellites is related to indicators seen on the previous domain.

To address these questions, Figures 5 (lower graphics) show the number of satellites proposed to be excluded from the positioning process. The implemented RAIM-FDE algorithm does not perform the exclusion of any satellite on data of the 16th of March, while for day 17th multiple satellites are excluded during different time periods of the day. The reason for this large difference lies in the contrast of distributions for the CNR, discussed in Section 3.2, which impact the weights determination during the positioning calculation contributing to decrease the internal consistency of the satellite within the model. Thus, the influence of disturbances on the ionosphere can be further appreciated in this domain, by changing the usability of several satellites. As the RAIM-FDE technique performs the exclusion of satellite based on the monitoring of the calculated positions, removing potentially hazardous satellites is expected to contribute to increase the overall accuracy of final solutions.

3.4 DGNSS Signal Domain

Tests in the DGNSS signal domain serves the evaluation of usability of provided correction terms. For these analyses the User Differential Range Error (UDRE) and the Pseudo-Range Residual (PRR) are considered as potential PKI's. The UDRE is a one-sigma estimate of the error due to noise and residual multipath and is determined at reference station (RS). The UDRE can be considered as PKI indicating the expected residual error (PRR) at any users after applying of correction data provided by RS. In ideal case, the PRR should be below the provided UDRE. Thus, the satellite specific behaviour of the UDRE and its relation with the PRR is investigated to determine whether the detection of blunders in the corrections becomes possible.

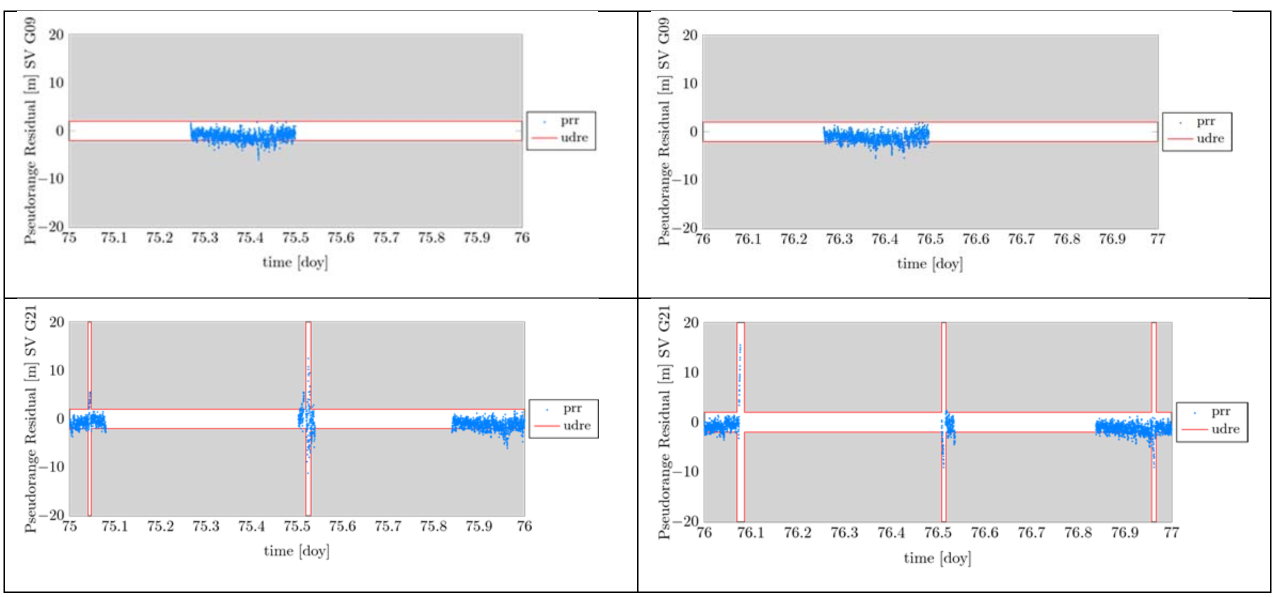

Figure 7: UDRE and PRR of PRN 09 and 21 at DoY 75 and 76 of year 2015

The first step for the evaluation of the corrections is performed at the *Service signal domain* with the analysis of the temporal variation of the PRR with respect to the obtained UDRE. Figure **Error! Reference**

source not found.6 (upper graphics) shows the calculated PRR for satellite GPS 09 at the IMS for the studied days. The overall behaviour of the PKI lies within the tolerable limits for both days, without sudden changes or large blunders, exemplifying how the behaviour of the PKI should look like for a satellite using healthy corrections. The obtained residuals for the satellite are bounded continuously by the reported UDRE, indicating not only high quality of the corrections but also that their errors are accounted by this PKI. On the other hand, Figure 6 (lower graphics) shows the calculated PRR for satellite GPS 21 at the studied days. Peaks with large amplitude for the indicator are noticed at doy 75 and 76 at the same time approximately, where the largest amplitudes are found at doy 76, exceeding the tolerance limit at several epochs. More noticeable events are detected at lunchtime at both days, where the magnitude of the PRR exceeds the tolerable limits. And indicator that either satellite or applied corrections are inconvenient for the positioning process. However, the behaviour of the UDRE for satellite GPS 21 shows nearly the same variability of the PRR along the day, reinforcing the possibility of bounding of errors during augmented positioning through the usage of the UDRE. As expected, the correlation of the two PKI is notorious during these time slots and drops in the quality of the UDRE, an evidence of the potential use of this indicator for the monitoring of the integrity of the used corrections.

3.5 DGNSS Position Domain

At the *DGNSS positioning domain*, the IMS acts as an artificial user to validate the feasibility of DGNSS based positioning and the performance of DGNSS based positioning in terms of position accuracy and availability. The evaluation of position accuracy is performed by comparing the determined position with the surveyed value of the user station. To quantify the improvement achieved while using augmentation services, the horizontal positioning error is calculated for the Standard Point Positioning service (Figures 7), as well as for the augmented C-DGNSS service (Figures 8) for the two desired days.

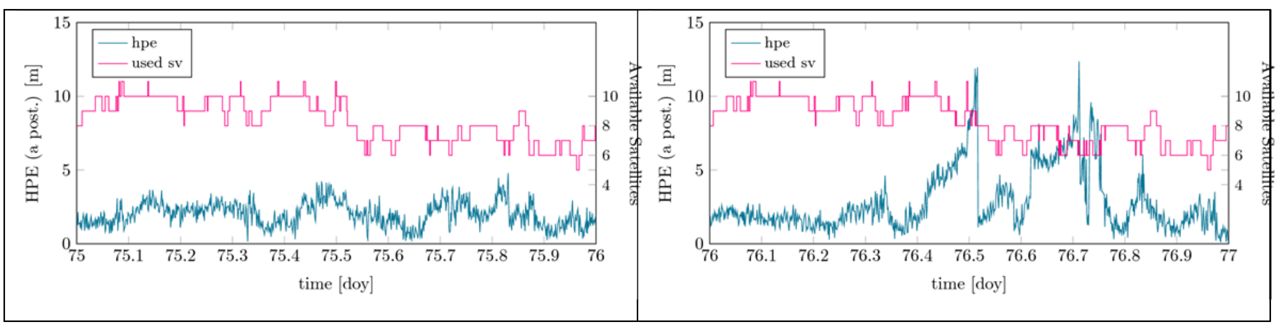

Figure 8: **Horizontal Position Error by application of SPP at DoY 75 and 76 of year 2015**

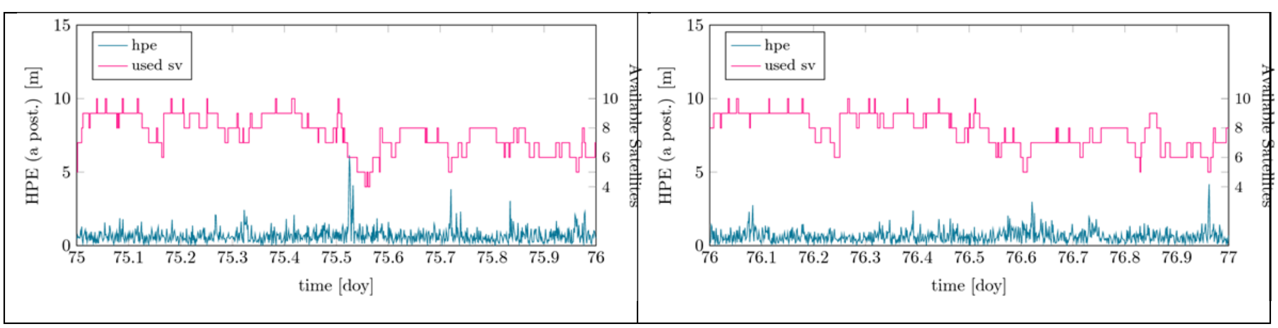

Figure 9: **Horizontal Position Error by application of C-DGNSS at DoY 75 and 76 of year 2015**

As expected, the positioning error for the Standard Point Positioning (Figure 7) service at the IMS lies often in the range of several metres. The overall performance for doy 75 (Figure 9) shows that the horizontal position error is better than 3m in almost 90% of the epochs (Figure 9, left). However, for doy 76, the HPE is drastically different (Figure 7, right), exhibiting values up to 13m in the time intervals [76.4, 76.5], and [76.6, 76.8].,At DoY 76 the horizontal positioning error is better than 3m in only 66% of available epochs (Figures 9). These results are consistent with the findings of the RAIM-FDE algorithm in Section 3.3. Maritime port operations demand horizontal positioning errors better than 1m. In this context the evaluation of the PKI in the different domains demonstrates the unsuitability of this service for such manoeuvres. The expected similarities on the available GNSS constellation for both days allowing to conclude, that an external factor, the ionosphere, is worsening the quality of the data and avoiding to meet the desired requirements with only this technique.

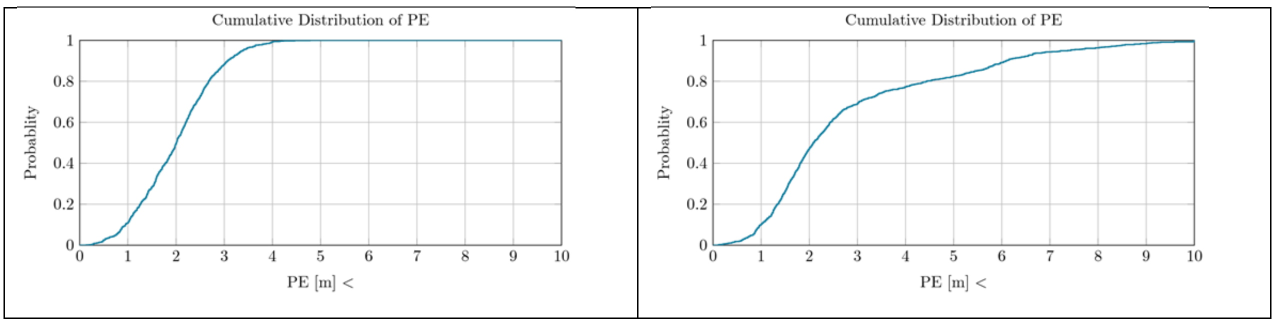

Figure 10: Cumulative distribution of HPE by application of SPP at DoY 75 and 76 of year 2015

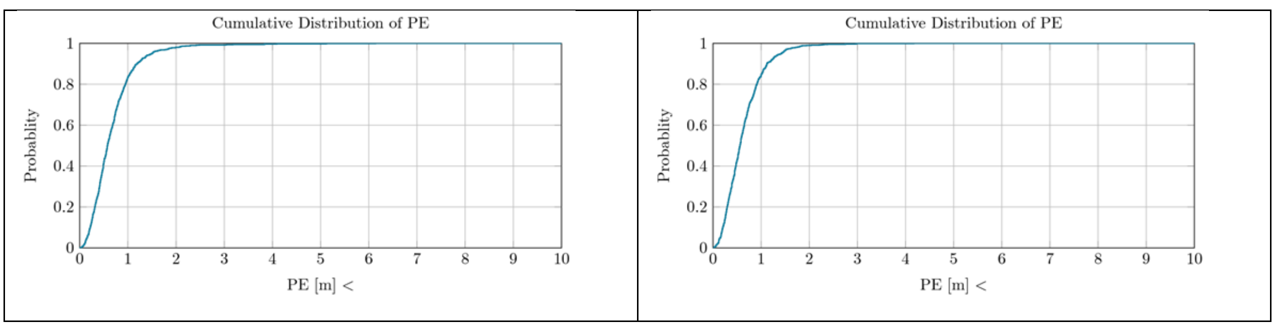

Figure 11: Cumulative distribution of HPE by application of C-DGNSS at DoY 75 and 76 of year 2015

Position determination using corrections of the C-DGNSS augmentation service results into significantly better results. The cumulative distribution of the positioning errors (Figures 8) shows that in approx. 90% of the epochs the error lies below 1m. However, the positioning error exceeds the 5m level around doy 75.55 (Figures 8). Several more representative large errors (greater than 3m) can be also observed at time 75.75, 75.85 and 75.5. These results are consistent with the observed behaviour of the UDRE and PRR presented in Section 3.4. Although for doy 76.6 and 76.8 (Figures 8) the overall performance is similar, results display -in smaller magnitude- the effect accounted in Section 3.3, where the satellites excluded by the RAIM-FDE process increase the amount of positioning error. For maritime port operations, the evaluation of the PKI in the different domains demonstrates the usability of the augmentation service.

Thus, it has been observed that the outliers detected by the different PKI at each domain are correlated in time. While is true the impact of disturbances on the DGNSS positioning domain is more evident, it is also notorious that the identification and exclusion of blunders on the information can be further analysed by the analysis of the different domains. These analyses also show the need for a continuous monitoring of the quality of the different positioning services, specifically in the presence of phenomena, such as the strong ionospheric activity registered at doy 76, which impacted the quality of the data significantly.

4. SUMMARY AND FUTURE ACTIVITIES

This paper has addressed investigations on error assessment in an augmentation system for GNSS positioning with maritime purposes. Based on four data processing domains (the GNSS signal, the GNSS position, the DGNSS signal and the DGNSS positioning domain) Performance Key Identifiers have been defined representing domain-specific challenges for augmented positioning. A special interest laid on their usability as basis for integrity monitoring of GNSS augmentation services. The analysis is based on real high-rate measurement data, using DLR´s experimental MGBAS platform in the research port Rostock.

At the GNSS signal domain, the CNR, and its dependency to the elevation angle, was characterised as the leading factor to determine the data quality. At the GNSS position domain the influence of the satellite geometry has been analysed using HDOP values. Additionally, the use of robust integrity algorithms, such as RAIM-FDE, was proven to contribute to the detection an exclusion of potentially hazardous measurements.

At the DGNSS signal domain, the use of UDRE as an indicator of the quality of the error has shown to be highly correlated to temporal variations of pseudorange errors. It was proven, that UDRE is an adequate tool to characterise blunders on the used corrections - especially on those epochs whose errors exceeded the maximum tolerable limits. Finally at the DGNSS position domain the analyses of the behaviour of the positioning error has shown to be able to demonstrate the usability of the augmentation service. It provides a comprehensive view of the influence of the errors on the different domains.

It has been shown, that site- and equipment-specific characteristics need to be considered for the application of the Performance Key Identifiers as they have a major impact on the overall performance of the system. Therefore long-time data analyses can be used to determine the nominal behaviour of the system as it is necessary for the characterisation of outliers.

The results confirm that the utilization of the proposed domains can increase the reliability and resilience of the provision of augmentation data. Performance Key Identifiers offer an opportunity for the real-time evaluation of augmentation services through the detection and isolation of individual errors on the different domains. It constitutes the first step towards the definition of an overarching integrity concept in the maritime domain. Future activities should focus on testing and validating the proposed concept for further maritime services such as additional augmentation services (e.g. Real Time Kinematics (RTK) or Precise Point Positioning (PPP)). This also includes the definition of additional Performance Key identifiers.

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