International Civil Aviation Organization

THE SIXTH MEETING OF IONOSPHERIC STUDIES TASK FORCE (ISTF/6)

Bangkok, Thailand, 19 – 21 January 2016

Agenda Item 4: **Review of deliveries of Tasks and related Action Items**

e) Task 5 - Iono Models

IONOSPHERE THREAT MODEL FOR GBAS

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SUMMARY

This paper presents guidance to develop ionosphere threat model for GBAS. It includes background, ionospheric impacts on GBAS and important parameters with viewpoints from safety analysis.

1. INTRODUCTION

1.1 GBAS (Ground-based Augmentation System) is a navigation system to support aircraft precision approach and landing. It is based on "local" differential positioning method which subtracts common error components from each GNSS ranging source signals received at user's onboard system. GBAS ground subsystem generates differential correction and integrity messages generally from four sets of ground GNSS antenna and receiver. As major error sources, it is well known that there are satellite ephemeris and clock errors, propagation delays due to ionosphere and troposphere, where refractivity is more than one. It is also an important fact that remained errors in each ranging source after the correction are increased in accordance with distance from the GBAS ground subsystem, namely centroid of four GNSS receivers. Multipath effects are also an error factor for GNSS differential technique, however, they could be reduced by averaging measurement data of ranging sources among four receivers.

1.2 It is expected that user's ionospheric delay is almost removed under nominal condition. However, range error due to ionospheric delay increases if there is a large spatial gradient between ground substation and user through "carrier smoothing processing", where carrier-smoothed pseudrange is calculated using carrier changes to reduce random noise of code measurement. This process increases an ionospheric range error because ionosphere delays code pseudrange whereas it advances carrier phase. Because absolute magnitudes of the both are almost the same, ionospheric error almost became twice in carrier-smoothed code under steady state against a smoothing time constant of 100 seconds. Another ionospheric effect is scintillation. It is caused by ionospheric irregularities with ionospheric disturbances and it produces rapid changes in received signal intensity and carrier phase measurement. Consequently, loss of lock might be frequently occurred during scintillation events and GBAS availability might be also significantly degraded.

2. IONOSPHERE CONDITIONS FOR GBAS SAFTY ANALYSIS

2.1 GBAS protects users under "nominal" ionosphere condition by differential correction messages and an evaluation parameter for ionospheric error (σ_{iono}), which is derived from a broadcasted parameter of σ_{vig} (sigma vertical ionospheric gradient). However, it is required to consider "anomalous ionosphere condition" in system safety design of GBAS ground subsystem, which is not bounded by σ_{iono}. Namely, anomalous ionospheric condition is defined as situation with larger positioning errors than protection levels, which indicate upper bounds of user's positioning error for horizontal and vertical directions derived from evaluation parameters for error sources in GBAS messages. To mitigate this ionospheric threat on GBAS, it is necessary to detect and exclude affected ranging sources at GBAS ground stations. Therefore, it is important to evaluate both nominal and anomalous conditions for system safety design against ionospheric effects.

2.2 Regarding nominal condition, Equatorial anomaly is a dominant factor to determine background ionospheric condition in the low magnetic latitude region. Ionospheric delay dynamically changes in day time and night time. It has seasonal variation, namely, spring and autumn are active seasons. It also depends on solar activity with a cycle of about 11 years. Such kind of effects should be covered by evaluation parameter of σ_{iono} (namely, σ_{vig}) although it depends on policy of system safety design. In generally, σ_{iono} should be determined to bound large number of observational data. Note that analysis only using observational data in a low solar activity period could lead underestimation.

2.3 Ionospheric anomaly condition is not bounded by protection levels. Storm enhanced Density (SED) is an extreme ionospheric density enhancement associated with severe magnetic storm. It is occurred at mid- to high latitude regions and its occurrence rate is relatively rare.
Plasma bubble is another disturbance summarized as ionospheric density depletion. It has a long structure along the north-south direction and produces steep ionospheric spatial gradients and scintillation on GNSS signals. It frequently occurs after sunset in high solar activity periods. In the Asia Pacific (APAC) region, its occurrence is higher during equinox seasons from March to April and from September to October than the other.

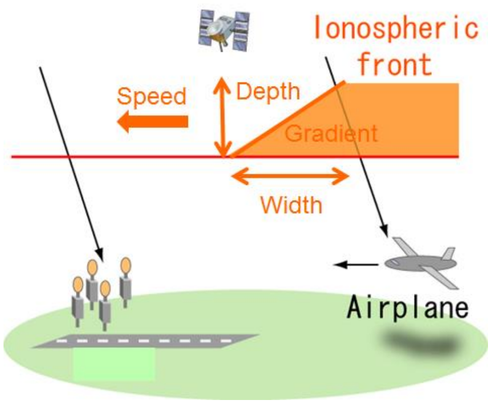
2.4 Definition of ionospheric threat model is required for system safety design. An ideal threat model should satisfy a necessary and sufficient condition for ionospheric effects on GBAS. Namely, underestimation exposes users to unsafe condition whereas overestimation significantly degrades system availability. Ionospheric front is a model with an ionospheric spatial gradient, is referred as ionospheric threat model and it is discussed in the next section.

3. DISCUSSION

Important parameters of describing ionospheric threat model

3.1 For safety assessment to implement GBAS approach service, it is required to validate if GBAS ground subsystem is enough to meet allocated SIS (Signal-in-Space) safety requirements or not. These requirements are described in ICAO Standards and Recommended Practices (SARPs). The SIS concept in CAT-I GBAS requires for ground subsystem to protect users from any ionospheric anomalies in “any” approach. Therefore, ground subsystem has to evaluate ionosphere-induced ranging source errors remained after GBAS correction including their impacts to final positioning errors at user side in order to generate appropriate broadcast parameters.

3.2 The remained ranging source error depends on geometrical relationship among ground subsystem, aircraft, ionospheric front location and GNSS signal propagation path location at ionospheric layer. The location of propagation path is referred as ionospheric pierce point (IPP) with assumption that ionosphere is a thickness less layer at an altitude of 350km (thin shell model). Ionospheric front model is described as four parameters of gradient (mm/km), moving speed (m/s), width (km) and depth (m) as shown Figure 1, and such parameter set is used for simulation of remained ranging source errors.



3.3 If ranges of the four parameters are given, remained ranging source errors are calculated by exhaustive analysis with various sets of their parameter values. Note that it is necessary to consider carrier smoothing time constant for the analysis. As mentioned above, ground subsystem for CAT-I GBAS has to protect users from any ionospheric anomalies. In a case of ionospheric front model, its threat space is described as assumed ranges for four parameters. Other important parameters of ionospheric threat model are described as localities, dominant season/time, occurrence rate and number of impacted satellites. Using the model, ground subsystem has to be designed to protect users against overall threat space by detection with integrity monitors and generation of safe broadcast parameter sets.

3.4 Because ground subsystem has to evaluate not only user's ranging source errors but also their final positioning errors, it performs a kind of position domain monitors in real time called as geometry screening in addition to integrity monitors for ranging source anomalies. Geometry screening is based on "potential" remained ranging source error using threat model and it validates various satellite geometry subsets which includes impacted satellites. Since GBAS parameters are set against potential error based on threat model, namely, system availability also depends on threat model.

Development and maintenance of ionosphere threat model

3.5 There are two approaches to develop ionospheric threat model. The first is observation-based approach, which is based on accumulated data enough to describe realistic features of ionospheric impacts on GBAS. Observation-based approach required to analyze two or more GNSS stations. In a case of dual frequency measurements for estimating ionospheric delay, it is needed to correct inter frequency biases. It is well known that an error component of estimated gradient increases in short baseline analysis because gradient is calculated from difference of ionospheric delay divided by baseline length. Moreover, baseline length should be comparable or smaller to spatial scale of disturbances. Because SED is disturbance related to magnetic storm, data filtering with index related to magnetic storm is useful for extraction of events. Plasma bubble is occurred with different mechanism. Therefore, such index parameters are not enough to extract events, but local time filtering is useful because it occurs in nighttime. Solar activity with a period of about 11 years is also an important factor for observation-based approach as mentioned above.

3.7 The second approach is simulation-based method. Arbitrary situations can be tested but validation is necessary based-on observations. This approach is useful to examine relationship between ionospheric spatial gradients and their impacts on GBAS with consideration of assumed three dimensional distributions of electron density and propagation paths of GNSS satellite instead of ionospheric front model, which is based on IPP.

3.8 Because safety management system requires monitoring and improvement even after implementation, long term validation of ionospheric threat model is an important issue. Through this process, there are possibilities not only to find new ionospheric events outside the current threat model but also to reduce threat space with improved safety margin. Solar cycle with different maximum activity is also an important viewpoint with consideration of fact that dense networks of GNSS continuous stations are deployed from 1990s.

3. ACTION REQUIRED BY THE MEETING

3.1 The meeting is invited to:

a) note ionospheric impacts on GBAS and necessity of appropriate threat model for safety analysis to implement GBAS in each region;

b) discuss observational and simulation approaches for development and long term evaluation of the ISTF ionospheric threat model; and

c) discuss any relevant matters as appropriate.

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