IONOSPHERIC CORRECTIONS FOR SATELLITE NAVIGATION USING EGNOS

Bertram Arbesser-Rastburg

European Space Agency, ESA-ESTEC, TOS-EEP,
Keplerlaan 1, NL-2200 AG Noordwijk, The Netherlands
E-mail: bertram.arbesser-rastburg@esa.int

ABSTRACT

EGNOS stands for "European Geostationary Navigation Overlay System". Its basic function is to enhance the navigation accuracy and to provide an integrity signal to the user. One of the major contributions to navigation errors in traditional single-frequency satellite navigation receivers is the ionospheric propagation delay. In this paper the EGNOS approach of improving the navigation solution using a ground network of reference stations and geostationary satellites is outlined.

INTRODUCTION

EGNOS is a regional augmentation system for satellite navigation using GPS and GLONASS and is interoperable with WAAS (in the US and Canada) and with MSAS (in Japan), designed improve the navigation accuracy and to provide a protection against hazardous misleading information to civil aviation users. EGNOS is a joint project of the European Space Agency (ESA), the European Commission (EC) and Eurocontrol, the European Organisation for the Safety of Air Navigation. It is Europe's contribution to the first stage of the global navigation satellite system (GNSS) and is a precursor to Galileo, the full global satellite navigation system under development in Europe. EGNOS provides a satellite-based navigation system to maintain required levels of safe operations in the European Civil Aviation Conference (ECAC) region. After completion it allow for replacement of VOR, DME, NDB, and most Category 1 ILS receivers with a single SBAS receiver. Improved safety when operating in reduced weather conditions due to precision vertical guidance on approach 3-dimensional position guidance for all phases of flight. The requirements are derived from RTCA Standards [1]. The systems utilizes a network of "ranging integrity monitoring stations" (RIMS) which provides a real-time measurement of total electron content along the path from each visible navigation satellite to the ground and transmits this information to the central processing facility (CPF).

IONOSPHERIC CORRECTION APPLIED BY GPS

The Global Positioning System (GPS) has been designed for use with dual frequency receivers, which can correct the ionospheric delay by calculating the total electron content from the differential delay Δt_2- Δt_1 :

$$TEC = \frac{(\Delta t_2 - \Delta t_1) f_1^2 f_2^2}{f_1^2 - f_2^2} \tag{1}$$

$$\Delta s_1 = \frac{40.3 \times TEC}{f_1^2} \tag{2}$$

In order to provide some additional information on the state of the ionosphere, a broadcast message is provided to the users. In this message, the state of the ionosphere is presented in a simple and elegant, eight parameter description based on the model developed by Klobuchar [2]. The procedure applied by the receiver, using the broadcast parameters α_i and β_i, is the following:

$$\Delta t_1 = A_1 + A_2 \cos[\frac{2\pi(t - A_3)}{A_4}] \tag{3}$$

where:
$A_1 = 5 \times 10^{-9}$ s

$A_2 = \alpha_1 + \alpha_2\ \varphi_{IP} + \alpha_3 \varphi_{IP}^2 + \alpha_4 \varphi_{IP}^3$
$A_3 = 14{:}00^h$ local time
$A_4 = \beta_1 + \beta_2\ \varphi_{IP} + \beta_3 \varphi_{IP}^2 + \beta_4 \varphi_{IP}^3$
$t = t_{UT} + \lambda_{IP} / 15$ (t_{UT} is UTC, IP is Ionospheric pierce point)
λ_{IP} is longitude of IP
φ_{IP} is the spherical distance of IP from geomagnetic pole

With the arrival of civilian consumer-grade navigation receivers, which only receive the C/A code at 1575.42 MHz (the “L1” frequency), this broadcast message suddenly became important, since it was the only information the user had to correct for the variable ionospheric effects. After May 2000, when selective availability (SA) was turned off, the residual ionospheric error was becoming very noticeable. The two main limitations of the approach is the simple representation of the ionosphere (roughly circular contours which rotate around the world along the geomagnetic equator) and the rather slow update rate of the broadcast message (up to six days delay).

IONOSPHERIC CORRECTION IN SATELLITE-BASED AUGMENTATION SYSTEMS

Satellite-based augmentation systems (SBAS) are designed to overcome the inherent limitations of a civilian GPS receiver: A network of reference stations inside and around the coverage area is providing continuous monitoring of the system errors, including the ionospheric group delay. The data are sent to the central processing facility (CPF) where the amount of signal delay and error is calculated for each instantaneous geometry and then translated to values at the nearest ionospheric grid point (IGP), which is a point on a regular latitude/longitude raster (see Figure 1). The grid points are spaced at 5 degrees latitude/ longitude; at latitudes greater or equal 75 degrees, the spacing is 10 degrees.

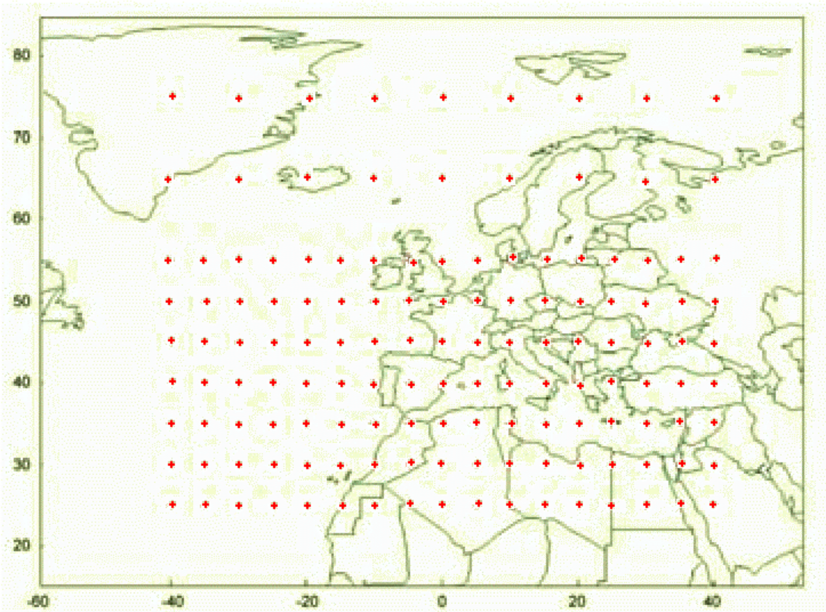

Figure 1: Ionospheric grid points within the ECAC region

The information on the ionospheric condition at the IGPs is then passed onto the user as a part of the SBAS navigation message. The user receives the Grid Ionospheric Vertical Delay (GIVD) which allows him to arrive at an improved navigation solution and he receives the Grid Ionospheric Vertical Error (GIVE) which provide him with the integrity information. At the same time, the information is stored in the database of the EGNOS System test-bed (ESTB) to allow for detailed analysis of the ionospheric behavior (the same happens in the US where the data are stored in the NSTB database).
The user terminal first determines the ionospheric pierce point which lies at the intersection of the line-of-sight link from the GPS satellite to user terminal antenna and the layer of highest electron density (this is assumed to be a sphere of 6728 km, equivalent to 350 km above the Earth’s surface). After determining the ionospheric pierce point, the user terminal selects the ionospheric grid points to be used for the ionospheric correction. Using a bi-linear interpolation, the ionospheric pierce-point vertical delay is calculated from the broadcast vertical delays of the surrounding IGPs. Once

the vertical ionospheric delay at the pierce-point location is established, the value is multiplied with the so-called obliquity factor to arrive at the ionospheric correction in the slant direction to the satellite. The obliquity factor $F_{pp}$is defined as below (eq. 3):

$$F_{pp} = \left[1 - \left(\frac{r_e \cos\varepsilon}{r_e + h_i} \right)^2 \right]^{-\frac{1}{2}} \tag{3}$$

where:
r_e = 6378.1363 km (approximate earth radius)
h_i = 350 km (height of the maximum electron density)
ε = elevation angle [deg]

The underlying geometry is shown in the sketch in Fig 2:

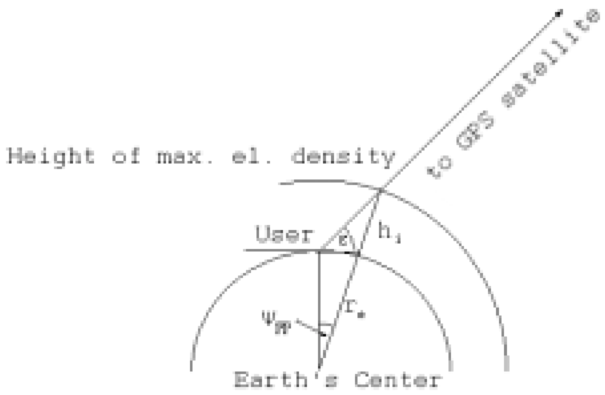

Figure 2: Geometry of ionospheric pierce point

THE EGNOS NETWORK OF MONITORING STATIONS

Name	Ctry	Code	Lat.	Long.	Name	Ctry	Code	Lat.	Long.
Alberg	DK	ALB	56.8 N	10.0 E	Mersa Matrouh	EG	MMT	31.1 N	27.1 E
Azores Islands	PT	ACR	38.3 N	28.0 W	Mourmansk	RU	MMK	68.5 N	33.0 E
Berlin	DE	BRN	52.32N	13.25E	Palma de Mallorca	ES	PDM	40.0 N	4.0 E
Canary Islands	ES	CNR1	28.3 N	14.1 W	Paris	FR	PAR	48.52N	2.20E
Catania	IT	CTN	37.0 N	15.0 E	Quebec	CA	QBC	47.0 N	71.5 W
Cork	IE	CRK	52.0 N	8.0 W	Reykjavik	IS	RKK	64.1 N	21.6 W
Cracovie	PT	CCV	50.0 N	20.0 E	Roma - Fucino	IT	ROM	42.0 N	14.0 E
Djerba	TN	DJA	34.0 N	11.0 E	Saint Petersbourg	RU	SPT	60.0 N	30.0 E
Feroe Islands	DK	FER	62.0 N	6.7 W	Santiago de Compostella	ES	SDC	42.8 0	8.3 W
Glasgow	GB	GLG	55.7 N	4.1 W	Singapore	SG	SGP	1.2 N	104 E
Hartebeeshoek	ZA	HBK	25.9 S	27.7 E	Sofia	BG	SOF	43.0 N	23.0 E
Konya	TR	KON	37.6 N	32.6 E	Stockholm	SE	STK	59.0 N	18.0 E
Kourou	GF	KOU	5.1 N	52.4 W	Tel Aviv	IL	TAV	31.8 N	34.8 E
Lisboa	PT	LSB	38.5 N	9.0 W	Toulouse	FR	TLS	43.4 N	1.3 E
London	GB	LON	52.0 N	0.0	Trondheim	NO	TRD	63.3 N	10.4 E
Madere	PT	MAD	32.4 N	17.1 W	Tromso	NO	TRO	69.5 N	19.0 E
Melilla	ES	MLA	35.4 N	3.0 W	Zürich	CH	ZUR	47.23N	8.33E

Table 1: Approximate locations of the EGNOS RIMS stations

EGNOS will become fully operational in 2004. A preliminary list of RIMS stations is given in Table 1. In the meantime, a test signal, broadcast by two Inmarsat satellites, allows potential users to acquaint themselves with the facility and test its usefulness. Currently, the EGNOS testbed consists of 12 RIMS as shown in Figure 3.

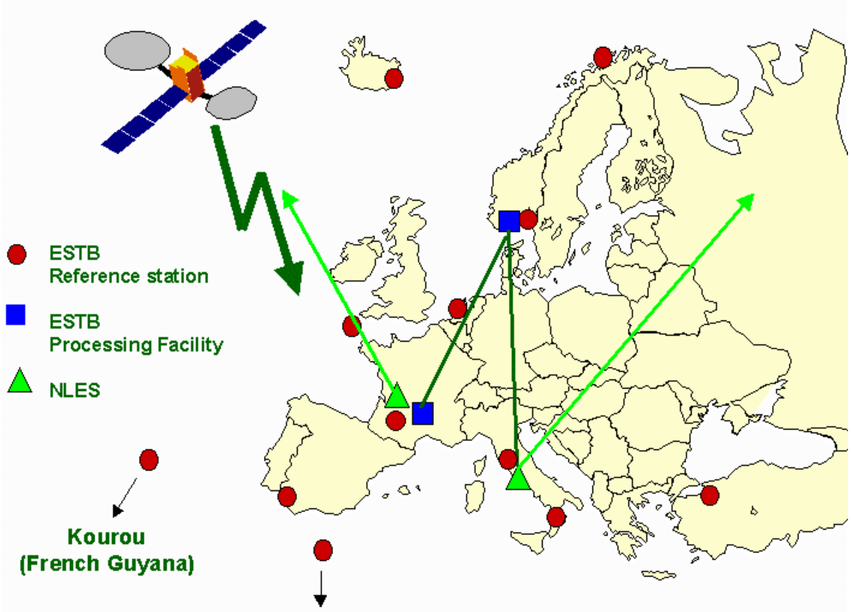

Figure 3: EGNOS System Test Bed (ESTB) Stations. (NLES stands for Navigation Land Earth Station)

VERIFICATION OF THE EGNOS IONOSPHERIC CORRECTION

The question as to whether the approach of transmitting ionospheric corrections as well as the model variance at ionospheric grid points is accurate enough to meet the accuracy and integrity requirements had to be tested before the actual system was deployed. In EGNOS this was done by providing four ionospheric worst case scenarios (equivalent to severe magnetic storm conditions) and applying these conditions to the EGNOS end-to-end simulator (EETES). These scenarios where produced from input data collected at Rutherford-Appleton Laboratory in the UK from existing experimental data for the European region and on modified average conditions based on ITU-R coefficients outside that region. The presence of traveling ionospheric disturbances was also simulated. Four scenarios has been chosen only on the basis of the geomagnetic conditions because it is not possible to define quantitatively the relation between geomagnetic storm and ionospheric storm conditions. Worst Case scenario 1 corresponds to a case that, on the basis of criteria grounded on geomagnetic indices, can occur in 0.1% of the time. Worst Cases scenarios 2 to 4 are expected to be representative of what can occur during 0.4% of the time. Case 2 corresponds to winter conditions, case 3 to equinoctial, and case 4 to summer conditions. The tests have shown, that the EGNOS system can handle strong ionospheric gradients without integrity violation.

CONCLUSIONS

EGNOS is providing users of satellite navigation a reliable improvement of the navigation solution and a solid protection against hazardous misleading information. The ionospheric correction has been tested in the simulator and more evidence of the reliability is currently collected in the EGNOS System Test Bed.

REFERENCES

[1] RTCA, Minimum Operational Performance Standards for Global Positioning System / Wide Area Augmentation System Airborne Equipment. 1999, RTCA Special Committee 159: Washington, D.C.

[2] J.A. Klobuchar, Ionospheric time-delay algorithm for single-frequency GPS users. IEEE Trans. Aerospace and Electronic Sys, 1987. AES-23: p. 325-331