Study of Ionospheric Scintillation at Low Latitude GPS Stations And Ephemeris Threat Models

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***Abstract*—Global positioning system (GPS) is a satellite based navigation system , which is developed by the Department of Defense (DOD) USA. GPS provides 3D position, velocity and time in all weather conditions. GPS position accuracy is limited by several error sources such as satellite ephermies, multipath effect, clock inaccuracies errors, ionospheric&tropospheric errors and relativistic errors. Among them the ionospheric error is the predominant one. Ionosphere scintillations can be limiting the GPS positional accuracy. Ionospheric scintillation is low frequency, random perturbations of the amplitude and/or phase of the carrier and code signals caused by very small irregularity structures in the ionosphere. In this paper, ionospheric scintillations are analyzed. For this purpose, data of dual frequency GPS receiver located in Hyderabad, Bangalore, Bhopal are considered. The preliminary results would be useful for developing now/forecasting ionospheric scintillation model over low latitude region and also Ephemeris treat models**

***Keywords*—GPS, Ionospheric Scintillations and TEC.**

I. INTRODUCTION

Small-scale irregularities in the electron content of the ionosphere, with spatial extents from a few meters to a few kilometers, can produce both refraction and diffraction effects on receiving GPS signals. The refraction changes the direction and speed of propagation of an electromagnetic wave while preserving the phase of the wave front. The diffraction, on the other hand, results in the wave front becoming irregular, through mutual interference, give rise to temporal fluctuations in the amplitude and phase of the received signal. Fluctuations due to either effect are called scintillations (Wanninger et.al, 1993). A radio wave traversing ionospheric irregularities consisting of unstable plasma waves or small-scale electron density gradients will experience phase and amplitude fluctuations. As long as the irregularities and the locations of the transmitter and receiver do not change, a single receiver at a fixed location would detect a constant amplitude and phase. In this paper amplitude scintillations and phase scintillations are studied. In the region of equator scintillations extends 30^0 on either side of the Earth's magnetic equator with the strongest effects at approximately 10^0 N and S. There is a clear diurnal variation: scintillations occur between sunset and midnight, and occasionally continue until dawn. In addition, there is a seasonal dependence (Wanninger, et.al 1993) in the longitude band stretching from the America to India, the effects are strongest between September and March. From April through August, there is only a small chance of significant scintillations in this region. In this paper three GPS stations (Hyderabad, Bangalore and Bhopal) data are used for studying ionospheric scintillation characteristics.

II. IONOSPHERIC SCINTILLATIONS

Scintillations are variations of amplitude, phase, polarization and angle of arrival produced when radio waves pass through electron density irregularities in the ionosphere (CCIR- 1992). These phenomena are produced by either one of the following types of irregularities:

- Sufficiently high electron density fluctuations at scale sizes comparable to the Fresnel zone dimension of the propagation path, or
- Sharp gradients of ambient electron density, especially in the direction transverse to the direction of propagation.

Small-scale ionospheric disturbances which have a few hundred meter scale sizes may cause phase and amplitude scintillations of the received GPS signal. In case of phase scintillations a sudden change in the phase occurs. Whereas in the case of amplitude scintillations degradation of the signal strength or even a loss-of-lock may occur (Conker et al., 2002). Scintillation effects are more severe during solar maximum years and in periods of heavy geomagnetic storms, mainly in equatorial and auroral regions. In mid-latitude regions the occurrence of ionospheric scintillation is extremely rare. They happen only once or twice during the 11-year solar cycle (Klobuchar and Doherty, 1998). However, in equatorial regions scintillation can be very strong and frequent, usually just after local sunset. Ionospheric scintillations are again divided into amplitude and phase scintillations. They represent a practical measure of amplitude and phase scintillations affecting the receiver.

A. Amplitude Scintillations

The strength of amplitude scintillation is given by the S4 index, defined as the root mean square of the variance of received power P divided by the mean value of the received power P (Bernhardtt et al, 2000).

$$S_4 = \frac{\sqrt{\langle P^2 \rangle - \langle P \rangle^2}}{\langle P \rangle}$$

where < > represents the average values.

B. Phase scintillations

Phase scintillation is the standard deviation of the signal phase over a given time interval. It is quantified by φrms or σφ which is given by

$$\sigma\varphi = \mathrm{Var}(\varphi) \qquad (2)$$

Phase scintillation occurs predominantly on the dayside in the cusp and in the nightside auroral oval.

1.1 Ephemeris Threat Models

Ground Based Augmentation Systems (GBAS), such as the Local Area Augmentation System (LAAS) being developed by the Federal Aviation Administration, use reference receivers at a single on-airport site to broadcast Pseudo range corrections for common-mode errors .Under nominal conditions, GPS satellite ephemeris errors are so small (typically 10 meters or less in 3D, with the along-track direction containing most of the error) that the differential pseudo range error between Ground Based Augmentation System (GBAS) reference receivers and users is negligible. However, this does not preclude the possibility that a failure will cause satellite ephemeris errors large enough to threaten GBAS. If this were to occur, the responsibility for detecting and excluding these failures would lie with the GBAS ground facility rather than with users. To the extent that the ground facility cannot do this, the user must be notified of the magnitude of the possible (undetectable) hazard so that his computed position protection levels include it. To help validate that GBAS can adequately protect against ephemeris threats, two classes of ephemeris failures have been identified . The failure class designated as "Type A" includes cases where the satellite moves away from its broadcast location due to an uncommanded maneuver, such as a thruster being fired on the satellite without a command being issued by the GPS Operational Control Segment (OCS). While a possible precedent for this type of event exists in the attitudecontrol thruster "glint firings" that have occurred on SVN's 15 and 18 during eclipse seasons and can cause standalone user range errors as large as 20 meters [4], the resulting errors are too small to concern GBAS. In order to cause errors significant to GBAS, one or more of the more-powerful orbit-maneuvering thrusters would have to fire without being commanded to, and the resulting satellite motion away from its nominal ephemeris would have to go undetected by OCS. Feedback from personnel2 inside and outside of OCS indicates that the uncommanded firing of one of the larger thrusters is extremely improbable because it cannot be triggered automatically and because multiple failures would have to occur on the satellite [5]. "Type B" failures, which are considered to be more credible but still very rare, include all cases where no unscheduled maneuver has occurred, but the ephemeris data broadcast is nevertheless incorrect. This event would most likely be caused either by an error in computing the broadcast ephemeris parameters or by corruption of the correct parameters somewhere along the line from OCS creation to OCS satellite uplink to satellite broadcast.Updated GPS navigation data is normally uploaded to each satellite once per day and is composed of 12 "frames" of data that are cycled through at two-hour intervals, with each ephemeris frame being fit to the satellite orbit over a four-hour interval surrounding its broadcast period . Thus, if a Type B fault were to occur, it would become evident at the time of switchover from an old (valid) frame to a new (anomalous) one. When this occurs, GBAS ground stations must validate the new data frame and switch from the old to new frame in its computed pseudo range corrections between 2 and 3 minutes after the new data is received or else exclude the satellite as unhealthy (users see an updated ephemeris CRC to notify them of the switchover and must switch at the same time). Prior to the introduction of ephemeris protection levels, GBAS ground systems were required to perform a series of sanity checks on navigation when satellites first rise into view and when data switch overs occur, and these monitors are collectively known as "Data Quality Monitoring" (DQM) . These checks confirm that the navigation data itself does not signal a problem and that the new data is consistent with other data (such as the current almanac data or the previous data frame) to within the limits of normal operations. A key contributor to these checks is the Message Field Range Test (MFRT), which simply confirms that the magnitude of the resulting pseudo range corrections is reasonable. Under nominal conditions and with S/A off, these corrections (which are basically the difference between measured pseudo range and computed range based on the broadcast ephemeris) should not exceed a magnitude of about 100 meters. If they do exceed 100 meters, and no other monitor flags have occurred on this satellite, then a large ephemeris error is a strong possibility. This is true for both Type A and Type B . However, MFRT only observes the component of ephemeris error in the satellite-to-ground-station line of sight; thus it is not guaranteed to detect all threatening ephemeris errors.This paper develops protection level equations for the ephemeris failure hypothesis that allow GBAS users to compute bounds on possible position errors due to ephemeris failures, provided that the GBAS ground facilities can establish bounds on the magnitude of potentially-undetected ephemeris failures. To establish this bound, a monitor concept has been developed that is Now known as the "Yesterday-minus-Today Ephemeris or "YE-TE" test.

III. Results and Discussions

Data from three GPS stations located at Hyderabad (17.360N,78.46^{0}E), Bangalore (12.98^{0}N,77.58^0 E), Bhopal (23.25^0 N, 77.42^{0}E) are considered for the analysis. The GPS data parameters such as GPS week, seconds of week, PRN number, elevation angle, azimuth angle, C/N0, S4, Phase scintillation index and TEC values are extracted from the GPS data. The scintillation index variations and other corresponding parameters such as elevation, phase scintillation, TEC and C/N0 with respect to GPS time (seconds of week) of satellite PRN No.1 observed at the Hyderabad station on 17th July 2004 is presented in Fig.1. From the figure, it can be seen that the maximum S4 values occurred at 16:46Hrs local time (558960s). At that time, C/No and Phase scintillation values are decreased, which is evident of strong scintillation. The intensity (S4 index) of the scintillation activity is stronger around the equatorial ionization anomaly (EIA) region in the Indian region. During the intense scintillation events, the GPS receiver is found to lose its lock reducing the number of satellites available which in turn decrease the probability of position ionospheric radio wave communications and the GPS-based navigation systems. Fig.2 show scintillation event observed at the Bangalore station on 17th July 2004 for the same satellite PRN No.1. It can be seen that, no scintillation activity observed during that time. Hence, scintillations are highly variable with respect to spatially and temporally. Fig.3 show scintillation event observed at the Bhopal station on 17th July 2003 for the same satellite PRN No.1. It can be seen that, a slight scintillation activity is observed during that time. Hence, scintillation occurrences are related to magnetic and solar activity (solar cycle), time of day, season and location.

3.1*YE-TE Concept and Capabilities*

The concept of the YE-TE test is simply to confirm that today's broadcast ephemeris data for each GPS satellite is correct by comparison with the most recent ephemeris data that has already been validated. For a satellite that is already in view and has an ephemeris frame change, the comparison is between the new and immediately previous sets of data, and under nominal conditions, these agree to within several meters during the 2-hour period within the "fit intervals" of both sets of data [3]. However, when a satellite first rises in view of the GBAS ground station, the most recent validated data is from the previous pass of that satellite and may be as much as 24 hours old. Thus, it is long past its "fit interval" and no longer precisely indicates the satellite location. Nevertheless, it is a valid basis for comparison within the limits of its accuracy. If the new ephemeris is dramatically in error, as in the "Type B" failure defined in Section 1.0, this comparison will detect the failure.YE-TE comparisons can be based on satellite positions computed from the old and new ephemerides or the individual orbit parameters of the old and new messages. The former approach is detailed in Sections 4.2 and 4.3, while the latter approach is introduced in Section 4.4. Note that the focus of both methods is on validating ephemerides for newly risen satellites. The impact of incorrectly rejecting a satellite with a healthy ephemeris is that the use of a healthy satellite is lost, but continuity is not affected because rejection would occur before the satellite is approved for use that day. Therefore, the YETE fault-free alarm probability need not be low enough to fit within the LGF continuity allocation. Instead, it should be small compared to the probability that a given satellite will be flagged unhealthy (and thus unusable) when it rises into view. Based on an analysis in [16], P_{FFA} can be set to 1.9 × 10^{-4} per newly risen satellite, which gives k_{FFA} = 3.73 provided that a Gaussian extrapolation can be used. During ephemeris changeovers for already-approved satellites, continuity is at risk if the satellite is rejected; thus P_{FFA} must fit within the overall continuity requirement of 8 × 10^{-6} per 15 seconds [14]. The nominal ephemeris differences are much lower in this case; thus this lower P_{FFA} does not require an increase in *MDE*.

IV. Conclusions

Ionospheric scintillations over low latitude plays crucial role in the performance of satellite based communications and navigation systems. In this paper, an ionospheric scintillation event result observed at Hyderabad station is presented. The probability of occurrences of such scintillation events will be analyzed. A model will be developed for now and forecasting the ionospheric scintillations. The outcome of the research work will be useful for the understanding the morphology of GPS ionospheric scintillation and in turn, it would be helpful for communication and navigation systems.

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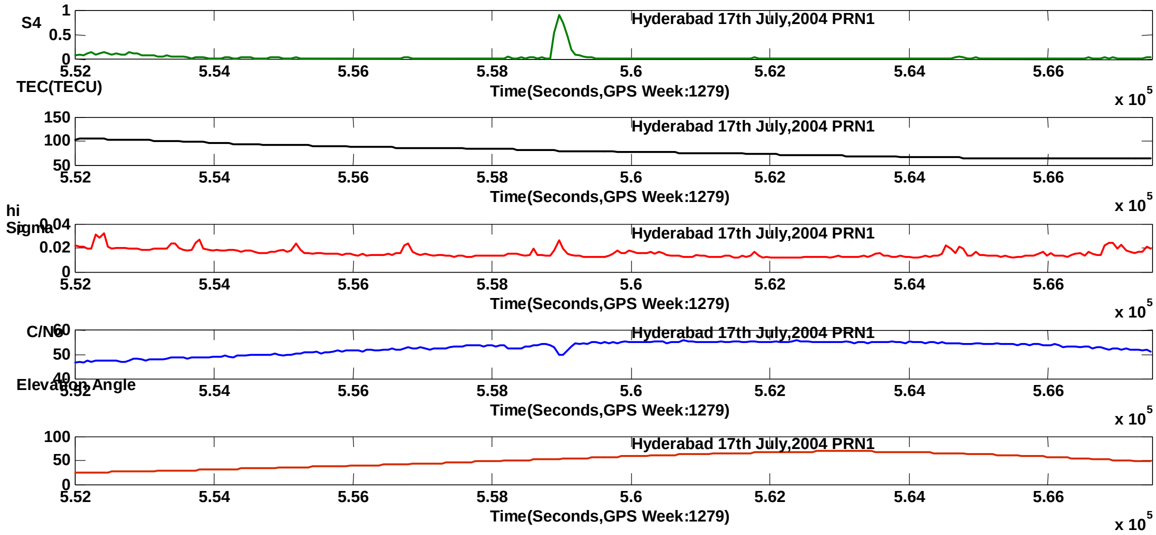

Fig.1. Ionospheric parameters observed by PRN N0.1 observed at Hyderabad Station.