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TEC based Phase Jitter for GNSS Receivers to Mitigate Ionospheric Threat

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1 Extended Abstract

Scintillation indices are often measured over one minute which for phase is the standard deviation in radians over this period and for amplitude (S4 index) the normalized standard deviation of the intensity. During the strong ionospheric scintillation, the intensity of a received GPS signal is reduced so that it sometimes falls below the sensitivity (threshold) of the receiver. The phase scintillation adds extra disturbance of phase to the received signal, also associated with the scintillation, can cause the carrier tracking loop, measured as phase jitter of a receiver. For generic GPS receiver, the phase jitter above 18°makes receiver to lose lock. In this work, an innovative approach for the estimation of phase jitter using the GPS observations from EUREF network is studied, and validated with period when strong and moderate ionospheric scintillation observed.

In the GPS receiver, the front end down-converts the GPS frequency to a lower intermediate frequency (IF) which is then used in acquisition and demodulation of the navigation data stream in the code and carrier tracking loops in order to determine the receiverâĂŹs position. The equation (1) mathematically represents the GPS signal (single frequency CA code) $S(t)$ at the IF frequency without any additional noise or ionospheric scintillation. However, during ionospheric scintillation, extra phase and/ or amplitude distort the GPS signal $S(t)$, modifying it to the new signal $R(t)$ as shown in equation (2):

$$S(t) = AC(t)D(t)\cos(\omega_{IF}t + \phi) \tag{1}$$

where A is the received amplitude, $C(t)$ is C/A code, ω_{IF} is the down converted (from $L1/L2$) carrier frequency, $D(t)$ is the navigation data bit at 50Hz sample rate and is ϕ phase due to Doppler.

$$R(t) = A\delta AC(t)D(t)\cos(\omega_{IF}t + \phi + \phi_I + \phi_o) \tag{2}$$

where δA and ϕ_I characterize extra amplitude and extra phase modulation due to ionospheric scintillation, while ϕ_o phase variation due to other sources; its effect is considered to be very small and so is neglected in this study. The $R(t)$ signal passes through the code and carrier tracking loop and then after the C/A code is removed using the code delay loop, the signal passes through the comparator in the carrier tracking loop. Basically, it compares the incoming phase ϕ_{IF}, and ϕ_f $\left(\phi_e = \phi_{IF} - \phi_f\right)$ generated by NCO (Numerically Control Oscillator), which is theoretically equal to the IF frequency. During phase scintillation, ϕ_{IF} (the phase in equation 2) can be very large and so also then is the phase error ϕ_e which of course depends on ϕ_f from the NCO. The value of ϕ_f can be controlled if one knows the scintillation level or at least have received some regional alarm index. Although it is not possible for generic GPS receivers to mitigate scintillation effects, studies have shown that ionospheric scintillation can be mitigated using GPS software receivers which basically update their loop parameters e.g. increasing the loop bandwidth based on some prediction models. In the carrier tracking loop of a receiver, the standard deviation of extra phase also known as phase jitter discussed above. Most of the exiting receivers are not capable of estimating the phase jitter, in our study we derived an innovative TEC based phase jitter using Kriging method. A geographic mesh map to indicate the phase jitter in the European region obtained to display the zone where the received signal is not properly tracked by the base stations. According to Kriging method, the value at an unsampled position could be estimated based on the values collected from its surrounding area. According to the estimated values, a mesh-map with higher resolution is generated to alarm the region that suffers a threat of cycle slip during ionospheric scintillation. The generated maps display the analogous phase scintillation indices via the data collected within every 5 minutes, and the level of threat is indicated in different colors. Referring to the mesh maps, the certain time range and global position where the GNSS signals has high risk of cycle slip and/or distortion could be predicted and summarised for alarm.

Over the last two decades, the strength of scintillation from ionospheric irregularities has been extensively studied using the time derivative of TEC (Total Electron Content) and this has been correlated with ionospheric

scintillation[1,2]. In a recent study, Tiwari et al. derived an analogous phase scintillation index $\sigma_{\phi a}$ (in radians) given in equation (3) using high pass filtered RoT at 1 Hz rate[3]. The study shows a good correlation with phase scintillation observed during geomagnetic storms in the high latitude region, together with its consequent standard deviation of phase jitter on the PLL loop of a GPS receiver during moderate to strong phase scintillation.

$$\sigma_{\phi a} = \left[\varpi \left(\chi \left(M \right), v_p \right) \times \sigma_{VTEC'_{HPF}} \right] \tag{3}$$

where $\varpi \left(\chi \left(M \right), v_p \right)$ is the elevation weighted function given in equation (4):

$$\varpi \left(\chi \left(M \right), v_p \right) = \frac{2\pi S \, 40.3}{cf} \times \left[\chi \left(M \right), v_p \right] \tag{4}$$

where S is a proportionality constant 0.003, and $\chi \left(M \right)$ is the mapping function in equation (5) and is based on SV elevation angle at two consecutive epochs, v_p is IPP velocity.

$$\chi \left(M \right) = \frac{1}{\left(M_i M_{i+1} \right)^2} \tag{5}$$

The derived index seems useful model for estimating standard deviation of phase jitter on a PLL as in equation (8)[3]. The Figure 1 illustrates result we obtained on 76th day of year 2015.

$$\left[\sigma_{R\phi} \right] = 1.8 \sigma_{\phi a} + 6.6 \tag{6}$$

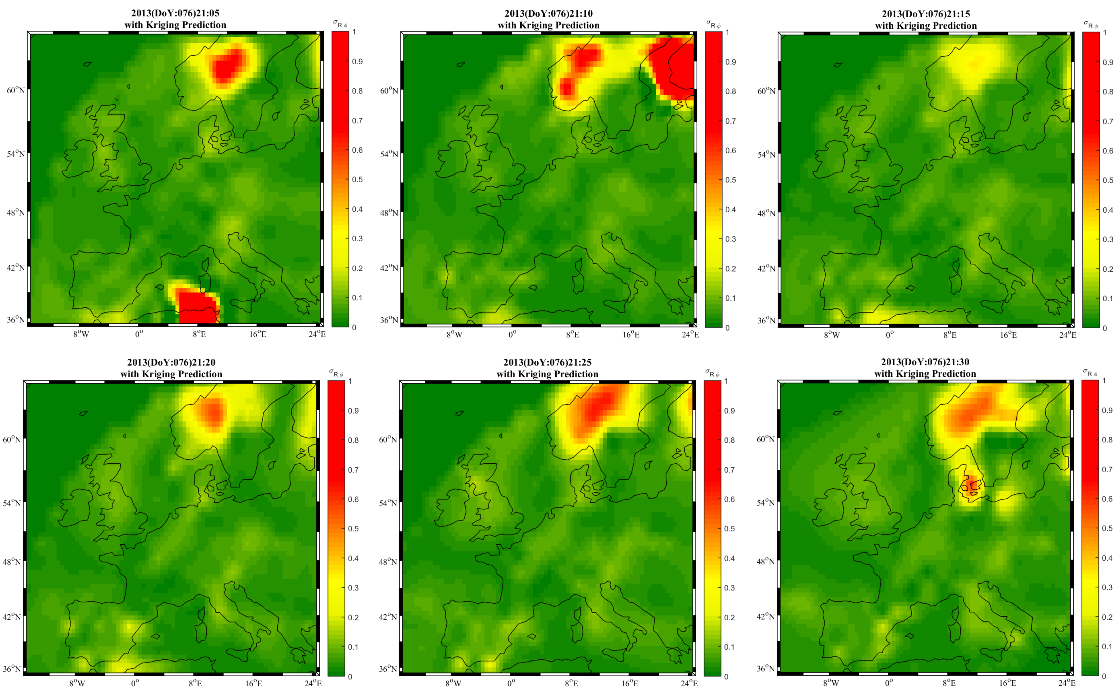

Figure 1. TEC based phase jitter (in degree) for European region.

References

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