Proceedings of the 23rd International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2010), **Portland, OR, September 2010, pp. 386-392.**

Elimination of superimposed Multipath effects on Scintillations index on solar quiet ionosphere at Low Latitude over the Kenyan Airspace from a lone Positioned SCINDA system

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ABSTRACT

In communication involving links between satellites and ground stations the most serious effects on trans-ionospheric radio signals is **scintillation.** By using satellite Navigation Systems such as Global Position System (GPS) receivers, we can probe the structure of electron density in the ionosphere and thus monitor scintillation of trans-ionospheric signals along the line of signal path in real time. In this study we show that for alone positioned navigation system such as the SCINDA system in Nairobi, multipath errors arising from satellites tracked at lower elevation angles can contribute significantly to radio scintillation rather than the ionospheric conditions along the signal path. Multipath errors inflate the scintillation values and falsely indicate ionospheric scintillation activity. For a quiet ionosphere, scintillation is proportional to the signal path and elevation angle of the satellite being tracked. By using data for the entire solar quiet period of 2009 (January-September), we created a fitting of the data to calibrate the multipath effects as outliers in the data at lower elevation. A separate plot for these outliers was then generated for every satellite track against elevation angles between 10 and 20 degrees.

Key words: Scintillation, Super-imposed multipath, quiet ionosphere, lower elevation.

INTRODUCTION.

The sun emits electromagnetic radiation over a wide spectral range by a continuous stream of plasma and burst of energetic particles. When the solar ultraviolet light impinges on the earth’s atmosphere, it ionizes a fraction of the neutral atmosphere. At altitudes **of about 80km above the** earth’s surface, collisions of neutral molecules results in rapid recombination and permanent ionized population of free electrons and ions called the ionosphere [Whitten, 1971]. The ionosphere is divided into three layers named D, E, F, with each layer referring to level of ionization within a given region. The ionosphere is the medium responsible for radio propagation and consequently, quality of radio communication, radiolocation and radio navigation. The density and the state of electron-ion component of the ionosphere depend very strongly on the degree of solar and geomagnetic activities, especially intensely increasing during solar flares. Intense solar activity level leads to disturbances in the ionosphere and which in turn leads to distortion of

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transionospheric signals. Irregularly structured ionospheric regions can cause diffraction and scattering of transionospheric radio signals when received at an antenna. Such signals have random temporal fluctuation in both amplitude and phase. This is mainly attributed to turbulences and irregularities of electron density in the ionosphere [P.Doherty, 2003]. This phenomenon is called scintillation.

Scintillation is strong at high latitudes, weak at middle latitudes and intense in the equatorial region [Portier-Fozzani and Nina, 2006]. During solar maximum period, scintillation is more frequent and more intense at all latitudes as the F-region of ionosphere ionizes. The magnitude of scintillation during solar minimum is greatly reduced mainly because of decreased background ionization density. At high latitudes, scintillation is mainly associated with large scale plasma structures. In the equatorial region it occurs at the time of sunset due to the effect of abrupt change in the ionospheric conductivity along the magnetic field lines which are nearly horizontal around this region. Large scale plasma bubbles are formed in the bottom side of the ionosphere and then rise to great height causing intense scintillation on trans-ionospheric radio signals [Groves K., 2007].

Monitoring of scintillation in real time can be achieved using the Scintillation Network and Decision Aid-GPS(SCINDA-GPS) receiver, which is a ground based receiver that can monitor scintillation at and L-band frequencies caused by electron density irregularities in the equatorial ionosphere [Carrano, 2007]. The SCINDA ground stations are generally positioned between the ionization crests of the Appleton anomaly, as these locations experience the strongest global levels of scintillation [Carrano, 2007]. In this work we show that during quiet ionospheric conditions, the diurnal variation of ionospheric scintillation is very minimal. We define a quiet ionosphere as that ionospheric condition where there are no external disturbances arising from external magnetic fields such as magnetic storms. We can equally refer to this period as quiet magnetic times.

PECULARITIES OF LOW-LATITUDE IONOSPHERE

In the day side ionosphere, the neutral wind normally sets up a polarization electric field which points into the eastward direction. At the magnetic dip equator where the magnetic field is exactly horizontal, this electric field results into ExB drift. This then leads to generation of a negative charge at the top and positive charge at the bottom of the ionospheric E-region. The resulting electric field prevents a further upward drift of electrons instead they are propelled westward by the eastward electric field. This westward movement of electrons constitutes an eastward electric current which is called the equatorial electrojet [Heelis, 2004]. The motion of the ions is largely inhibited at this altitude due to their collisions with neutral gas. A way from the magnetic dip equator where the geomagnetic field is not quite horizontal the electric field associated with the equatorial electrojet is communicated along the magnetic field to the F-region, where it drives the plasma upward by day and downward by night. This phenomenon is the so called electrodynamic lifting. Since the lifting operates across the field lines rather than along them, the plasma is able to descend again along the magnetic field. This event does characterize the low latitude ionosphere(equatorial ionosphere) and is best known as the equatorial anomaly [Groves K., 2007, P.Doherty,2003]. The anomaly is characterized by a trough at the magnetic equator and two humps at 15 degrees on either side of the magnetic equator. The persistence of the equatorial anomaly into the night depending on the season and solar activity is known to be produced by the evening enhancement in the eastward electric field generated by the F-region dynamo action resulting from the eastward component of the thermospheric wind blowing in the region of the decreasing day and night E-layer Pederson conductivity distribution[Heelis, 2004, Zhao B., *et al*. 2009]. The development and decay of equatorial anomaly produce a large latitudinal disturbances of F-region plasma in the lower latitude belt in the post sunset hours. This effect contributes to the enhanced ionospheric scintillation effects produced by the plasma bubble irregularities on trans-ionospheric radio wave propagation[Zhao B., *et al.* 2009].

For this period of 2009, scintillation of the ionosphere has not been very common but a few occurrences have been noted especially at the early hours of the day between 7-9 hours Local Time. From our observation of daily ionospheric profilers such as TEC and S4 index, the ionosphere tends to maintain the same pattern of behavior over this period of solar quiet moment. We describe the solar quiet ionosphere as the state of the ionosphere during low magnetic activity levels.

MULTI-PATH ERROR IN SATELLITE SIGNAL TRACKING

Multipath refers to the phenomenon of a signal reaching an antenna via two or more paths. Typically an antenna receives the direct (i.e line of sight) signal and one or more of its reflections from structures in the vicinity and from ground. A reflected signal is usually delayed and weaker than a direct signal. This can thus translate into errors in measurement of such signals. This work does show that alone positioned system is most vulnerable to errors related to multipath effect especially at lower elevation angles. While by tracking only satellites above 20 degrees such errors can be limited, this work has shown that for alone positioned system the number satellites tracked above 20 degrees reduces in number

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thus limiting the understanding of spatial distribution of scintillation effects on signal tracking by the ionosphere.

SCINTILLATION MEASUREMENTS BY SCINDA-GPS SYSTEM.

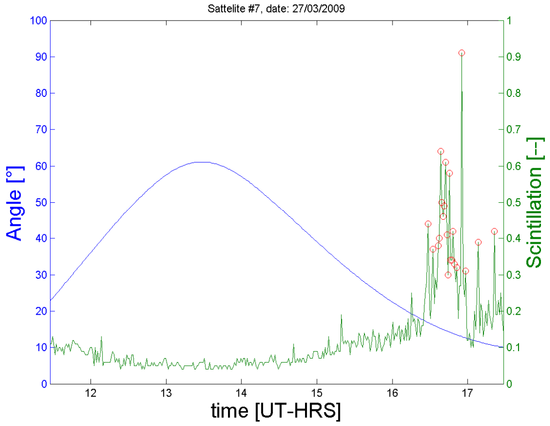
The Scinda-GPS receiver measures the scintillation index on both L1 and L2 signals, never the less when a GPS receiver is tracking the encrypted P(Y) code using codeless or semi-codeless techniques the measurement of carrier to noise on L2 is compromised [Carrano, 2007]. Hence computed scintillation intensity on L2 is not reliable and is usually ignored except when using a military GPS receiver that has been keyed to interpret the encrypted P(Y) code. Ionospheric scintillation is characterized by rapid fluctuations in the amplitude and phase of trans-ionospheric radio signals due to variations in the local index of refraction along the propagation path. The SCINDA-GPS system measures the intensity of amplitude scintillation given by the scintillation intensity index S_4 as [Carrano S, 2007, Groves K., 2007]. Values of scintillation index greater than 0.3 are considered as ionospheric scintillation.

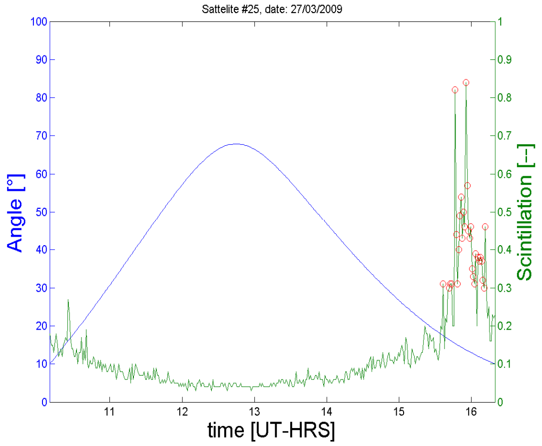
$$S_4 = \frac{\sqrt{\left\langle I^2 \right\rangle - \left\langle I \right\rangle^2}}{\left\langle I \right\rangle} \qquad (1)$$

Where I represents the signal intensity (amplitude squared).

DATA ANALYSIS.

This analysis does show that while tracking a single satellite in the entire day on quiet time ionosphere, scintillation seems to be occurring on satellites tracked at lower elevation angles as indicated below. We identify scintillation events at s4 values greater than 0.3 and are marked with red pops on the plots below.





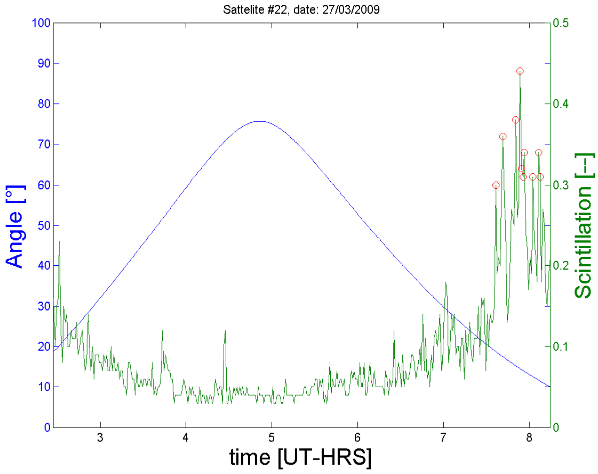


Figure 1: superimposed multipath error shown along individual satellite (signal) path at lower elevation marked in red pops.

From the satellites shown in figure 1, scintillation occurrences which have been marked in red were all captured only at lower elevation of below 20 degrees. Satellites tracked at angles above 20 degrees did not show any form of scintillation occurring as shown. Taking all the satellites tracked for the entire day and plotting scatter chart of scintillation versus their position as they rise and set over the Kenya Airspace, then the distribution of scintillation index at elevation angles less than 20 degrees broadens considerably while the absolute value becomes larger as shown below in figure 2 below;

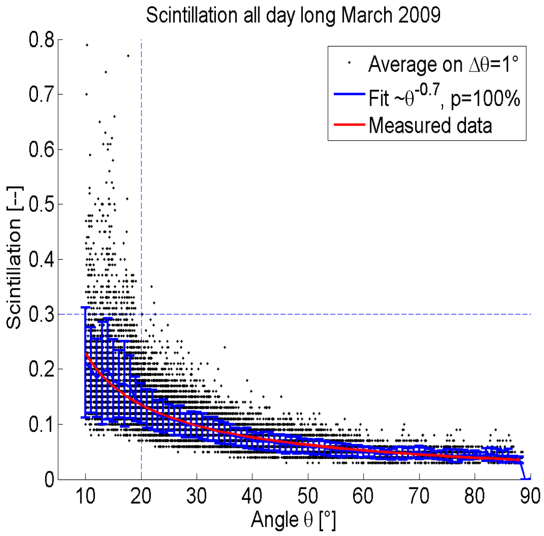


Figure 2: Average Scintillation activity for the entire day the whole month of March, 2009 .

Considering only scintillation measurement at night or day time separately, the picture does not change although the atmosphere is expected to be more turbulent at night.

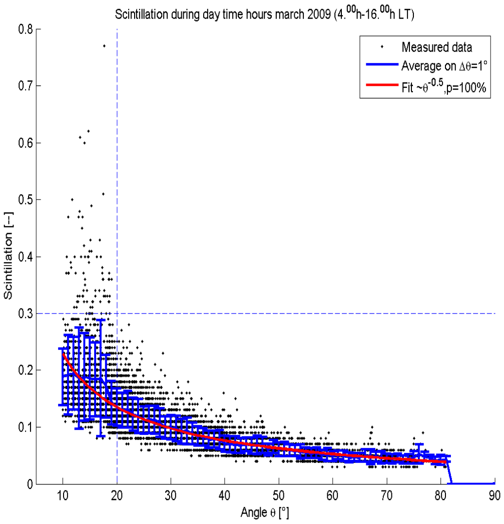


Figure 3: Scintillation during day time btw 7am-7pm Local time for entire month of March 2009.

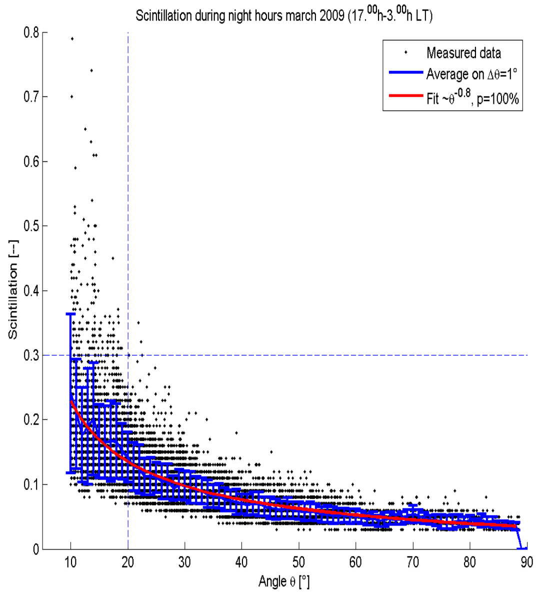


Figure 4: Scintillation during nighttime btw 8pm-6am Local time for the entire Month of March 2009.

To eliminate the multipath at lower elevation we consider now tracking satellite only above a minimum elevation angle of 20 degrees. While this reduces the errors related to multipath, with alone positioned system the satellites tracked reduces significantly as shown below in figure 6 and the error arising from multipath effects is reduced significantly as illustrated in figure 5 below.

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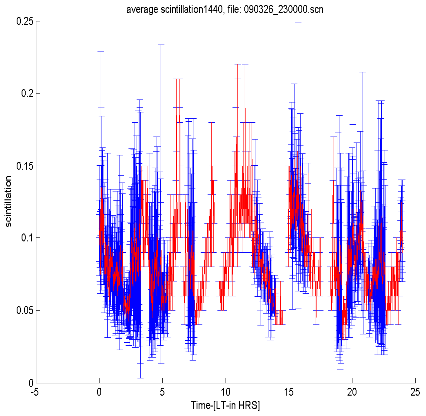


Figure 5: Scintillation for satellites captured above 20 degrees

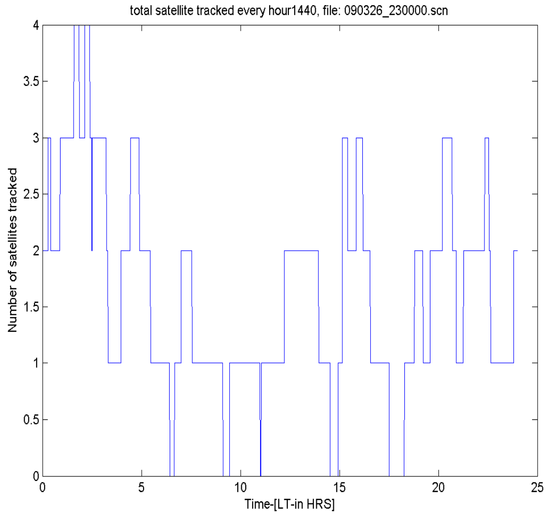


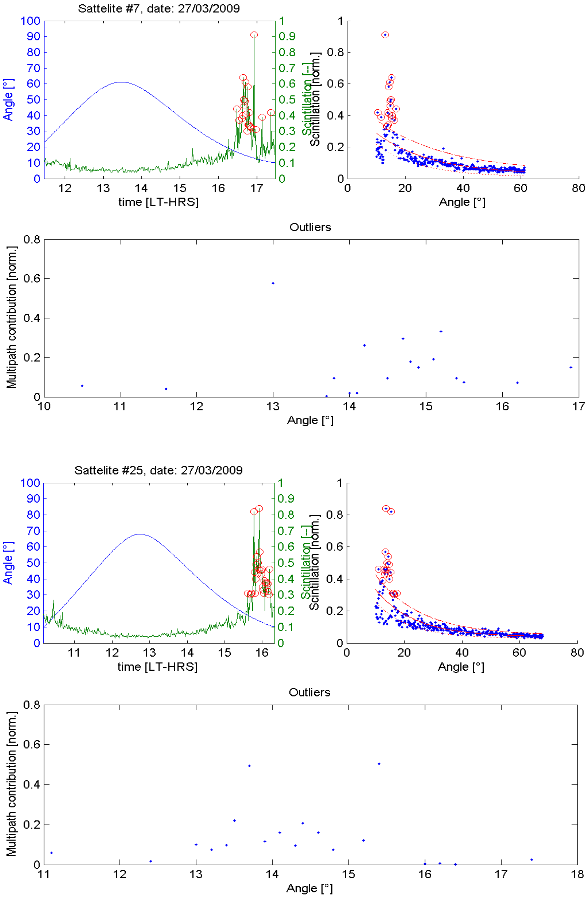
Figure 6: Number of Locked Satellite above 20 degrees

CALIBRATION OF SCINTILLATION INDEX VALUES AT LOWER ELEVATION TO ELIMINATE MULTIPATH ERRORS AS OUTLIERS IN THE DATA.

The main source of errors which affect the scintillation index at lower elevation in a loned positioned SCINDA system such as the one used in this study is superimposed multipath errors which inflate the scintillation values and falsely indicate ionospheric scintillation activity as can be seen in figures 1 above. Based on our plots in figures 2, 3 and 4, scintillation varies with the angle of elevation exponentially in the form of the equation (2) below. This equation has been generated by the raw data from the Scinda system.

$$a\exp(-bx)+c \tag{2}$$

Where a, b, c are fitting parameters and x is the position of the satelliete as they rise and set over this region. Based on this relation and using data for each and every satellite, we created a fitting of the data to calibrate the multipath effects. We implemented this fit on every satellite to eliminate multipath effects as outliers as shown in figure 7 below:



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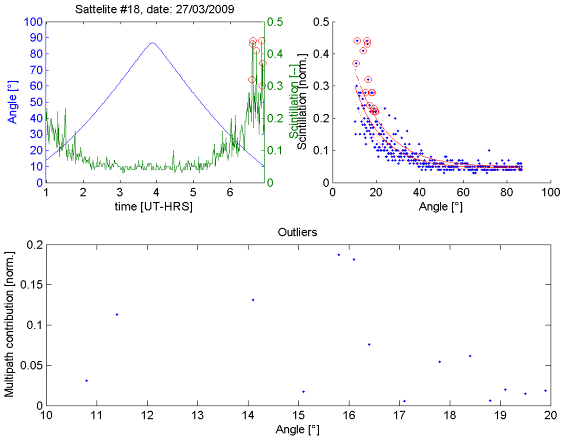

Figure 7: Eliminating multipath effect as outliers

The procedure is as follows: we make the assumption that the ionospheric scintillation is proportional to the signal path and the elevation angle of the satellite being tracked. Thus the fitting parameter c in equation (2) above signifies the base scintillation of satellite when it is directly overhead (elevation about 90 degrees), while b is equivalent to the attenuation coefficient (which we can now refer to as scintillation coefficient). If we fit this equation to all scintillation data above 20 degrees where we can neglect multipath errors we get the magnitude of the coefficients as well as their incertitude. Taking the worst (which leads to maximal estimated scintillation) incertitude value and extrapolating towards smaller angles (dashed line in figure 7 above) we can estimate the magnitude of multipath contribution as well. This is shown in figure 7 in the plot of outliers.

CONCLUSION AND RECCOMENDATION

Studies in ionospheric scintillation using a single receiver GPS system can be complicated at lower elevation due to superimposed multipath effects which inflate the scintillation index values and falsely indicating ionospheric scintillation activity. While by considering only satellite constellation above lower elevation of 20 degrees could eliminate multipath error; for a single receiver such as our station in Nairobi, the constellation of satellites reduces thus limiting the understanding of spatial distribution of ionospheric conditions. To improve on studies of ionospheric irregularities using alone positioned navigation system, we need to consider the elimination of superimposed multipath errors at lower elevation angles.

ACKNOWLEDGEMENT

We appreciate the Air Force Research Laboratory Collaboration for the donation and maintenance of the SCINDA-GPS system at the University of Nairobi and Boston College for the Technical Training in satellite Navigation and Technology.

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