Impact of tropospheric turbulence on low elevation GEO and LEO earth-space links

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Unmanned Aerial System (UAS) technologies are considered as an interesting solution for defence and custom applications but also for various civilian applications such as monitoring of the earth resources, fire detection and monitoring as well as environmental and meteorological missions. Frequencies in the Ku and Ka-band are envisaged, for the download of large amounts of data. Earth-Observation satellites are carrying a large number of instruments that necessitate a very high data rate for the data transfer to the ground stations during the visibility period of the satellite and as a consequence they need a large bandwidth and a high frequency. Ka-band frequencies around 26 GHz are dedicated to this application. The rapid variation of the elevation angle and the high velocity of the satellite showed the necessity of having space-time models for the description of the various tropospheric effects.

1. Specific characteristics of the UAV and LEO radiolinks

The link from Unmanned Air Vehicle (UAV) to the ground station can reach very low elevation angles and very high length that render it different from the classical earth-space links and from classical terrestrial links. The limitations of the ITU-R models [1] and [2] have been stressed [3] and improved models have been proposed for rain [4] and gaseous [5] attenuation.

The radio links between earth station and Earth Observation satellites exhibit rapid variations in the elevation angle during the visibility period of the satellite and scans the half plane above the earth station. This necessitates the full characterization of the meteorological status of the troposphere in space en time during the crossing of the satellite. This was not necessary for GEO satellites earth links for which the frozen troposphere was used, transforming the time variations measured in space variations.

2. Models available for UAV and LEO radiolinks in a turbulent environment and their limitations

For very low elevation angles, both scintillation due to tropospheric turbulence and multipath are observed. This is included in the model available in [1] and a new model [6] has been introduced to improve the transition. A new model has been proposed by ONERA [7] for the calculation of multipath and scintillation at low elevations, using phase screens. This model is based on the assumption that the properties used by the Kolmogorov turbulence theory are valid. It has however to be stressed that, going to very low elevation angles, the transverse direction becomes vertical in place of horizontal in the classical earth-space links. Some authors have noticed that the outer scale of turbulence was not the same in the vertical and the horizontal plane and that the turbulent layers are thin. This will influence the validity of the hypotheses and the formula for the calculation of variance and spectrum. No direct measurements are available: radiosondes are scarce both in space and time and their vertical resolution is around 50m and 10m for high resolution radiosondes.

A simple method for calculating the statistics for LEO satellites is proposed in [1], using the statistics conditional to the elevation angle. This model can be applied to gases and rain statistics, as well as to scintillation. For LEO satellites, the velocity of the satellite modifies the dynamics of the signal. Dividing the elevation angles in various bins, we can consider that the statistics of scintillation amplitude can be calculated in each elevation angle bin. The hypothesis of frozen turbulence cannot be used for the full passage of the satellite but well in each angle bin. So, if the sampling frequency is large enough, the amplitude of the variations are well reproduced and the statistics of amplitude are correct. The dynamics of the signal depends on the satellite velocity and on the turbulent structures of the troposphere.

Furthermore, not only statistics, but also time series are needed for the design of those systems. In the absence of measurements, “reasonable” methods have been proposed in order to help the designers. Michelson and Liu have proposed a channel simulator (time series) for attenuation and scintillation, using the properties obtained in GEO satellites measurements [8]. Their method is based on two parameters: the scintillation variance in function of elevation angle and the corner frequency that is proportional to the transverse velocity of the satellite for LEO orbits. This model can be used for “clear sky scintillation” but there is no way to reconstruct the combination of rain and scintillation. The whole theory of wet scintillation has been developed for geostationary satellites and the separation of rain and scintillation is based on the fact that the spectrum has a flat region between the low frequency part due to rain and the -8/3 slope due to turbulence. The calculation of the spectrum is however an issue because it is only meaningful on a stationary period. The length of the stationary period is not known in the case of LEO satellites.

An in depth analysis will be proposed in the final paper, for various orbits, checking the possibility to separate/combine the two effects.

3. Characterization of the tropospheric turbulence

In order to check the validity of the classical hypotheses used for the calculation of scintillation, it is proposed to use the meso-scale Numerical Weather Forecast (NWF) models to generate the behaviour of the troposphere. The model is constrained every 6 hours using re-analysis databases (at 0.5° resolution) and 2/3 successive grid nests are necessary to reach the target resolution (about 1 km in horizontal plane and 100 m in vertical direction). A first evaluation of the C_n^2 parameter has been performed on horizontal planes at various heights and is presented in Figure 1, for the centre of Belgium. Further evaluations in the vertical direction will be presented.

The outputs of NWF models are 3D-structures giving pressure, temperature and humidity versus time can also be used for the propagation of radiowaves at very low elevation angles.

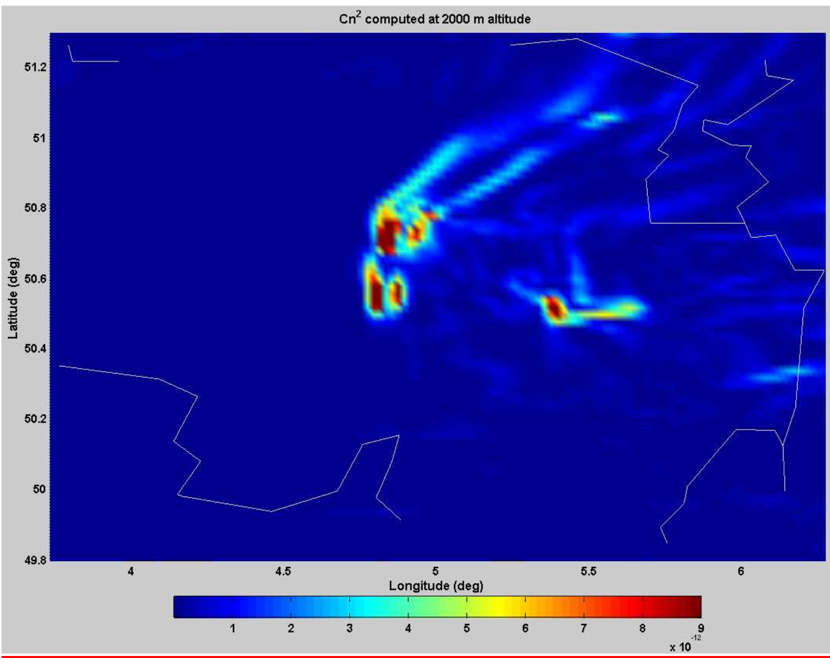

Figure 1: C_n^2 calculated on a grid of 3 km at an altitude of 2000m, above Belgium

4. Conclusion

This paper presents a preliminary analysis of the limitations of the existing models for the calculation of scintillation in the case of low elevation and LEO links. The possibility of using Numerical Weather Forecast models for better characterising the troposphere and further calculating the propagation of radiowaves is envisaged.

The final paper will present preliminary results of the calculation of the refractive index structure constant using the output of a meso-scale Numerical Weather Forecast model and a preliminary analysis of the spatial and temporal variability of this parameter.

5. References

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