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Mesoscale High-resolution Meteorological and Radiative Transfer Models for Satellite Downlink Budget Design at Millimeter-wave Frequencies

Deep space (DS) missions for interplanetary explorations are aimed at acquiring information about the solar system and its composition. To achieve this result a radio link is established between the space satellite and receiving stations on the Earth. Significant channel capacity must be guaranteed to such spacecraft-to-Earth link considering their large separation distance as well. Terrestrial atmospheric impairments on the space-to-Earth propagating signals are the major responsible for the signal degradation thus reducing the link's channel temporal availability. Considering the saturation and the limited bandwidth of the conventional systems used working at X-band (around 8.4 GHz), frequencies above Ku-band (12-18 GHz) are being used and currently explored for next future DS missions. For example, the ESA mission EUCLID, planned to be launched in 2020 to reach Sun-Earth Lagrange point L2, will use the K-band (at 25.5-27 GHz). The BepiColombo (BC) ESA mission to Mercury, planned to be launched in 2016, will use Ka-band (at 32-34 GHz) with some modules operating at X-band too. The W-band is also being investigated for space communications (Lucente et al., IEEE Systems J., 2008) as well as near-infrared band for DS links (Luini at al., 3rd IWOW, 2014; Cesarone et al., ICSOS, 2011).

If compared with X-band channels, higher frequency bands can provide an appealing data rate and signal-to-noise ratio in free space due to the squared-frequency law increase of antenna directivity within the downlink budget (for the same physical antenna size). In particular, W-band (75–110 GHz) can be one valid alternative to K- and Ka-bands; theoretically, W-band should provide high channel capacities due to the large bandwidth availability and a more robust immunity to signal interference. However, atmospheric path attenuation can be significant for higher frequencies since the major source of transmission outage is not only caused by convective rainfall, as it happens for lower frequencies too, but even non-precipitating clouds and moderate precipitation produced by stratiform rain events are detrimental. This means that accurate channel models are necessary for DS mission data link design. A physical approach can offer advanced radiopropagation models to take into account the effects due to atmospheric gases, clouds and precipitation.

The objective of this work is to couple a weather forecast numerical model with a microphysically-oriented radiopropagation model, providing a description of the atmospheric state and of its effects on a DS downlink. This work is the continuation of a study developed in the framework of the RadioMeteorological Operations Planner (RMOP) program, aimed at performing a feasibility study for the BC mission (Biscarini et al., EuCAP 2014). The RMOP chain for the link budget computation is composed by three modules: weather forecast (WFM), radio propagation (RPM) and downlink budget (DBM). WFM is aimed at providing an atmospheric state vector. Among the available weather forecast models, for RMOP purposes we have used the Mesoscale Model 5. The output of the WFM is the input of the RPM for the computation of the atmospheric attenuation and sky-noise temperature at the receiving ground station antenna. RPM makes use of radiative transfer solver, based on the Eddington approximations well as accurate scattering models. Time series of attenuation and sky-noise temperature coming from the RPM are converted into probability density functions and then ingested by the DBM to compute the received data volume (DV). RMOP project was originally aimed at investigating the Ka-band for DS mission focusing the attention on the advantages of using a coupled WFM-RPM approach with respect to climatological statistics in a link budget optimization procedure. In this work we extended the study to the W- and K- band. The signal degradation, due to atmospheric effects in DS links in terms of received DV, is investigated and a comparison among K-, Ka-, W- and the more commonly used X-band is carried out. The quality of the DS downlink will be given in terms of received DV and the results at different frequencies compared showing the respective advantages and drawbacks.