URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

Weather-forecast-based fade mitigation for Ka-band satellite links: optimization and validation using Hayabusa-2 deep-space measurements

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The increasing need of wider bandwidths, the requirements of smaller spacecraft antennas and the congestion of typically adopted microwave frequency bands (e.g., the X band) are pushing space missions towards higher frequencies such as the Ka band and above. The main drawback of using high microwave frequencies is the signal degradation, caused by the atmospheric constituents (e.g., rain, clouds and gases), that can be of more than one order of magnitude larger than the one occurring at X band. This requires the development of specific fade mitigation techniques.

This work presents a weather-forecast-based fade mitigation developed for deep-space communications operating at Ka-band (26.5 - 40 GHz): the RadioMeteorological Operations Prediction (RadioMetOP) model. RadioMetOP is based on the statistical prediction of the atmospheric and radiometeorological scene expected during the satellite-to-Earth transmission period and allows the satellite link-budget design through the optimization of the transmission data-rate. The model performs numerical weather predictions for the meteorological scene expected during the satellite transmission and, through the solution of the radiative transfer problem, converts predicted meteorological variables into radiopropagation variables (i.e., atmospheric attenuation and sky-noise temperature) used for the link-budget design and optimization.

A feasibility study of the RadioMetOP model was presented in [1] where, although very promising results were achieved, weather forecasts were performed in a deterministic framework, i.e., without an estimate of their uncertainty. Indeed, several meteorological scenarios may be possible and the weather forecast should reflect this through its uncertainty. Our attempt in this work is to quantify this forecast uncertainty through a stochastic approach: we have developed a space-time ensemble method resorting to the temporal evolution of the predicted meteorological variables over the spatial grid of the weather-forecast model. This stochastic approach tackles the so-called space-time double penalty of a model forecast, that is, the error that can arise from predicting an atmospheric phenomenon correctly in time, but in the incorrect place or, vice versa, correctly in space but at the incorrect time. The other limitation of the approach proposed in [1] was that the lack of Ka-band measurements prevented any kind of validation. Hayabusa-2, one of the first deep-space missions using the Ka-band for the downlink-transmission, is a mission to the asteroid 162173 Ryugu, launched in 2014 by the Japan aerospace exploration agency (JAXA) and supported by the European space agency (ESA). In this work we have the great possibility of exploiting Ka-band measurements, available from Hayabusa-2 mission, to validate the RadioMetOP model. Some preliminary results were presented in [2] where two test-cases among Hayabusa-2 transmission days (passes) were analyzed. We will provide a systematic analysis exploiting the mission dataset over a period of more about 5 months. During this period, RadioMetOP model was run in an operative mode providing forecasted link-budget optimizations just before each Hayabusa-2 pass. After each pass, RadioMetOP optimization results were analyzed and validated through a comparison with Hayabusa-2 measurements: the RadioMetOP accuracy was estimated and the advantage of this stochastic weather-forecast-based approach was quantified in terms of data-rate (i.e., in terms of transmitted data-volume). These results will pave the way to the operative applicability of the proposed weather-forecast-based mitigation technique to Ka-band (and above) satellite missions.

The authors gratefully acknowledge JAXA team for allowing the collaboration within Hayabusa-2 mission.

References

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