Synthetized Tropospheric Total Attenuation Time Series for Satellite-to-Aeronautical Link From L to Q Band

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***Abstract*—The synthetized attenuation time series together with the Complementary Cumulative Distribution Function of attenuation values play a crucial role for the design and validation of communication systems. ITU-R recommendations propose different models to characterize the channels. In particular, the ITU-R P1853 recommendation proposes a methodology for the synthesis of attenuation time series for ground stations. Starting from this recommendation and combining different recommendations and external models, this manuscript proposes a synthetized time series for the total attenuation for airborne platforms. The synthetized time series includes the combination of platform movements in the three dimensions and in the microwave frequency range.**

***Index Terms*—Attenuation time series, airborne systems, link budget**

I. INTRODUCTION

Satellite services for aeronautical communication are currently available for different purposes: from passenger entertainment to aircraft data transmission up to Air Traffic Management (ATM) [1]. For this purpose the characterization of the aircraft-to-space link is crucial to guarantee all the proposed services. Due to the limitation in space, weight and dimension in airborne systems, the channel characterization is crucial and several contributions have to be considered, such as: atmosphere, aircraft attitude and ground scattering [2]. During the flight, the propagation terms affect the communication channel with different impact. For this reason, only an accurate analysis based on simulated time series can provide precise simulations of the link budget.

Among the different parameters affecting the aeronautical link, the presence of the atmosphere plays a crucial role. As for all the ground-to-space links, the different layers of the atmosphere induce propagation impairments in the microwave frequencies bands. The two main effects are due to the ionosphere and the troposphere layers. As far as the ionosphere is concerned, the ionization activity induced by the sun disturbs the propagation of signal below a few GHz. On the other hand, the troposphere is the layer where the weather events will impact the microwave signals in X band and above. At these frequencies, the turbulent air masses and rain cause power absorption and fast fluctuations.

The manuscript focuses on the effect of the troposphere in the aeronautical-to-space link, proposing a combination of ITU-R recommendations developed mostly for a ground-to-space link and adapting them for aeronautical scenario.

Models are defined to evaluate the tropospheric propagation taking into account the variability in both time and space domain [3]. The models require several ancillary information which are available in terms of databases based on long terms observations and statistical representation.

Two main recommendations are used for the proposed model: the ITU-R P1853-1 [4] which defines models for the tropospheric total attenuation time series synthesis, and the ITU-R P2041 [5] which predicts the various propagation effects for planning airborne systems links.

II. STRUCTURE OF THE MODEL

A. General Overview

The model developed is based on the ITU-R P1853, which proposes time series synthesis methods for all the propagation effects: rain, clouds, water vapor, oxygen and scintillation. In general, the approach proposed by the ITU-R P1853 is based on the definition of three White Gaussian Noise (WGN) time series, which are combined and tuned according to geographically-based statistical parameters.

The white Gaussian noises are defined at the beginning of the process, while the tuning parameters are updated according to the position of the receiver using databases defined in other ITU-R recommendations which will be mentioned in the next section.

The ITU-R P1853 recommendation is defined for a ground-to-space link and it does not take into consideration the altitude effects. The model, presented in this manuscript, encompasses this aspect, proposing altitude dependencies of all the tropospheric attenuation effects.

The proposed altitude dependence models are based on recommendation ITU-R P2041 which is defined to predict the various propagation effects in an airborne systems in Space-to-Airborne and Airborne-to-Ground scenario.

An overview of the proposed model will be included in a layout figure in the final paper where all the input parameters will be reported and connected with all the recommendations of interest.

As proposed in ITU-R P 1853, the total attenuation time series is obtained as the sum of all the single attenuation time series.

B. Model for the altitude variation

As anticipated, the crucial aspect of the aeronautical-to-space channel model is the altitude dependence of the tropospheric effects. Considering a typical commercial aircraft flight, it results that most of the flight time is spent at altitudes above the troposphere where most of its effects are negligible, but during the phases of take-off, climb and then descend, approach and landing, the troposphere effects become crucial and relevant, in particular if adverse weather conditions are encountered.

The altitude dependence effects are defined considering two main aspects: altitude thresholds and altitude scaling.

The altitude thresholds are defined in order to null the contribution of a propagation effect above a certain altitude. On the other hand, the altitude scaling is the model that reduces the contribution effect because the aircraft is flying in the propagation media at a certain altitude. To better understand the approach an intuitive example of an airplane crossing the clouds is considered. When the aircraft is under the clouds, the entire clouds contribution is considered, while when the aircraft enters the clouds, the effect is reduced proportionally to the percentage of signal path in the cloud. Finally, once the aircraft exits above the clouds, this specific contribution is null.

1) Altitude Thresholds

Some of the propagation effects are limited in altitude, it means that above a certain altitude the specific effect is null. This is valid for: rain, clouds, water vapor and scintillation.

The altitude threshold is not defined for the oxygen, which remains the only effect in cruise phases.

The rain threshold is defined according to the ITU-R P 839 [6], which provides a global map for the altitude of the zero degree Celsius isotherm and the relation with the rain altitude.

As far as the cloud threshold is defined, this is based on the vertical dimension of the cloud itself. This threshold is not fixed but it is function of the liquid water content and the vertical development of the cloud. The two crucial parameters are the cloud base and the cloud top. The model used to define these two parameters is based on the approach proposed in [7], where the cloud vertical profile is defined by analytical expressions based on CloudSat observations [8]. Since rain and clouds are strongly correlated, the cloud base is defined at the rain height.

The scintillation is also related with clouds and for this reason, its threshold corresponds to the cloud base.

Finally, the water vapor threshold is defined according to the troposphere extension. Since more than 99% of the water vapor is present in the troposphere, the troposphere height is modeled as function geographic position and period of the year, and above the troposphere the water vapor contribution is null.

2) Altitude Scaling

Since the aircraft is flying in the propagation medium, its effect is scaled according to the flight altitude and the attenuation is proportional to the only percentage of the signal crossing the medium.

Since there is a linear relationship between the signal path and the attenuation expressed in dB, the models proposed in ITU-R P 1835 are used by considering the aircraft altitude instead of the ground altitude as for the terrestrial systems.

III. VALIDATION RESULTS

In this section validation tests have been performed to validate the described atmospheric tool. The first steps of the validation analysis have been carried out by comparing the Complementary Cumulative Distribution Function (CCDF) with the ESA software RAPIDS II, version PASTEL [9]. RAPIDS II is a web-based software for the characterization of space communication links based on ITU-R recommendations models, where outputs are the attenuation statistic curves of the different propagation parameters.

The first test is the horizontal validation, it has been performed in order to evaluate the use of a single AWGN and the tuning effects by changing the position of the receiver on the ground. The second validation test is based by considering the receiver at fixed altitudes without varying the geographic coordinates. Then, the third test is based on the comparison of the time series at different frequencies, and finally, an example of the application of the tropospheric time series is presented using as input a real flight path of a commercial flight.

A. Horizontal Validation

The first validation analysis was based on the comparison of the total attenuation CCDF of the atmospheric time series with RAPIDS II. The tropospheric tool has been used to generate a very long time series, in order to be statistically valid for a fixed position.

A single time series has been defined to represent the attenuation of a receiver that stays for a statistically significant time in a position and then moved instantaneously in a different position. Figure 1 depicts the long term time series for four selected locations characterized by different climate zones: Oslo, NO, Munich, DE, Toulouse, F and Dakar SN.

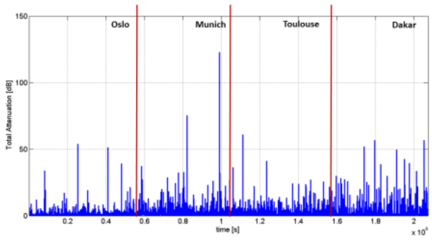

Figure 1. Overview of the horizontal validation time series

The very long time series for a single site is used to generate the corresponding CCDF curve and then compared with the RAPIDS II curve. Figure 2 depicts the comparison between the two methodologies.

The comparison shows a good agreement between the two methods, with a bias of a few dBs, which is justified due to the different combination of the rain and cloud attenuations between the two simulations. The ITU-R P1853 defines a method for the combination of the two effects which are included in the troposphere tool but is not in RAPIDS II.

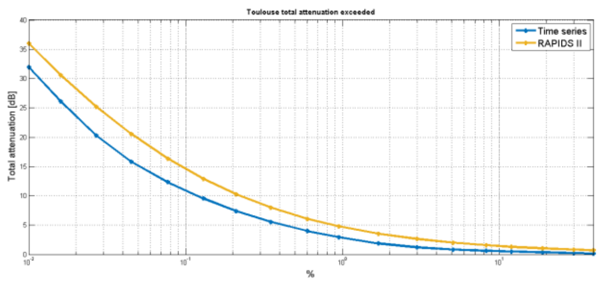

Figure 2. Comparison of the CCDF of the total attenuation between RAPIDS II and the proposed atmospheric tool for Toulouse

B. Vertical Validation

A second validation test has been carried out using the same approach as in the horizontal validation, but in this case, the receiver has been placed at a mid-air position and not on the ground. The comparison of the CCDF is reported in Figure 3. The time series has been generated at an altitude of 3 km taking into consideration only the rain, oxygen and water vapor.

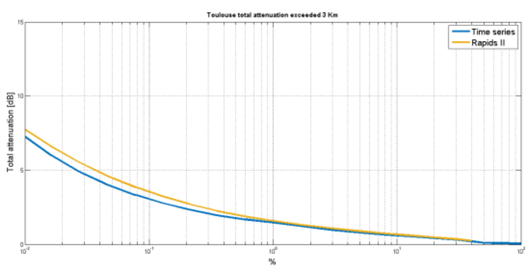

Figure 3. Comparison of the CCDF of the total attenuation between RAPIDS II and the proposed atmospheric tool in Toulouse at 3 km altitude

C. Frequency Dependance

The third validation analysis has been carried out by comparing the output of the models at different frequencies. This analysis is based on the selection of a significant WGN profile and using it at different frequencies. The generated time series are reported in Figure 4, where the curves correspond to 10 GHz, 26 GHz and 50 GHz, respectively. Together with the different order of magnitude of the attenuation, it is also possible to see the strong correlation between all the effects. In particular, rain is present when there are clouds and the scintillation effect during a rain event is linked to the attenuation level [10]. As far as the scintillation is concerned, it should be pointed out that the model used considers the receiver as a ground station, an update including the airplane dynamic will be include in the final paper.

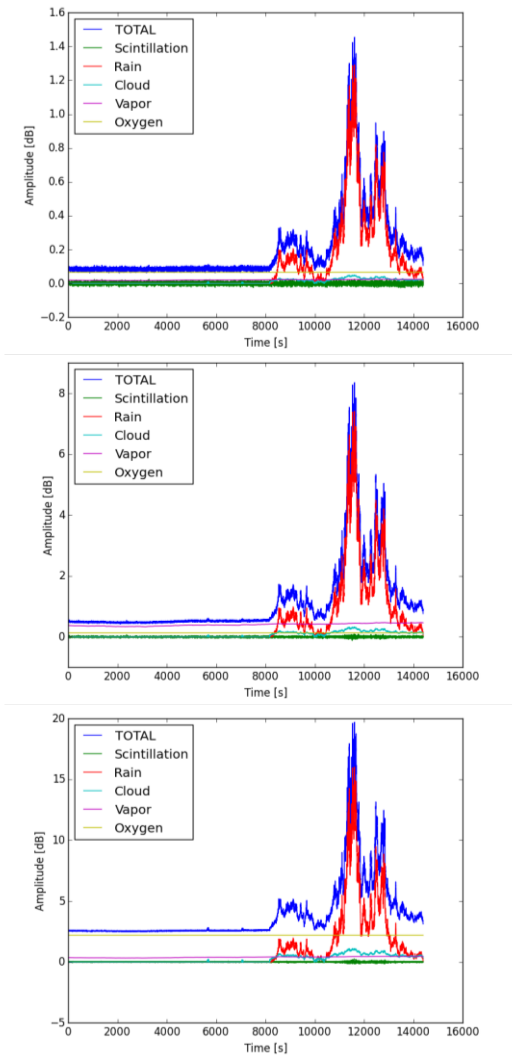

Figure 4. Comparison of the attenuation profiles for respectively, 10 GHz, 26 GHz and 50 GHz in Toulouse, F.

The analysis demonstrates a good agreement with the model output and the expected behavior. First of all, increasing the frequency, the attenuation increases. Moreover, the obtained orders of magnitude of the attenuation components are coherent with the expected values as demonstrated by comparison with RAPIDS II tools.

D. Flight Path Example

Finally, the atmospheric tool is used to generate the time series based on real flight path of commercial aircrafts. In this analysis a European regional flight between Rome Fiumicino, Italy and Stockholm Arlanda, Sweden is used. The flight path coordinates and altitudes have been acquired from Flight Aware.

The simulation time corresponds to the combination of all the flight time plus a few minutes on the ground at the beginning and at the end, to represent the taxiing on the ground at the two airports.

Figure 5 depicts the attenuation effects during the flight. The random generation of the WGN results with a clear sky day in Rome and rainy conditions in Stockholm, with a strong combination of all the effects.

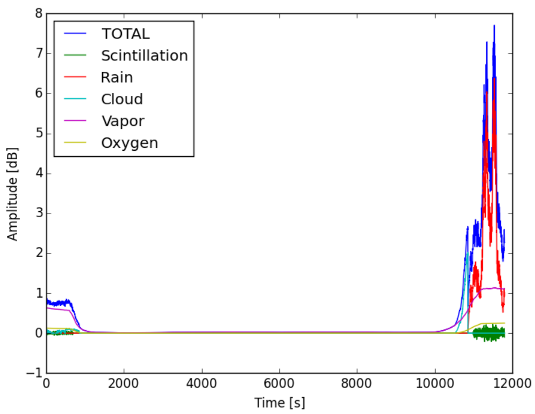

Figure 5. Example of attenuation contributions during a commercial flight from Rome to Stockholm.

IV. CONCLUSIONS

The atmospheric tool has been implemented for the validation of aeronautical-to-space link. The architecture of the tool is based on ITU-R recommendations in order to be versatile and to be used worldwide. As demonstrated in the validation analysis, the result of this architectural decision is that the tool is not limited only to aeronautical applications, but it could be used for all kind of receivers: from ground stations to maritime and terrestrial vehicles.

On the other hand, the use of ITU-R databases smooths the variability of the parameters of interest, reducing the corresponding high frequency part of the atmospheric fluctuations.

Further updates are foreseen to increase the accuracy of the simulated atmosphere and further analysis will be carried out considering different scenario and different flight paths.

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