

RAPIDS II-version PASTEL: a user friendly software for the analysis of space communication

Carlos Pereira¹, Danielle Vanhoenacker Janvier¹, Belen Montenegro-Villacieros¹, Michael Cheffena², Laurent Castanet³, Benoit Segart⁴, Luc Lechien⁵ and Antonio Martellucci⁶

¹ ICTEAM, Université Catholique de Louvain, Place du Levant 3, bte L5.03.02, Louvain-La-Neuve, B1348, Belgium, email: carlos.pereira@uclouvain.be, danielle.vanhoenacker@uclouvain.be, belen.montenegro@uclouvain.be

² Gjøvik University College, Teknologivn. 22, N-2815 Gjøvik, Norway, email: michael.cheffena@hig.no

³ ONERA, 2 Avenue Edouard Belin, F31055 Toulouse Cedex4, France, email: Laurent.Castanet@onera.fr

⁴ UNIWAY SA, Lenneke Marelaan 12/1, B 1932 St-Stevens-Woluwe, Belgium, email: jeanpierre.vanloo@uniway.be

⁵ AETHIS SA, Parc Scientifique Einstein, Rue du Bosquet 7, Louvain-la-Neuve, B1348, Belgium, email: luc.lechien@aethis.com

⁶ TOS-EEP, ESA, ESTEC, Keplerlaan 1, PB 299, NL-2200 AG Noordwijk, The Netherlands, email: Antonio.Martellucci@esa.int

Abstract—Telecommunication, Navigation and Earth Observation systems used worldwide, have space segments operating in various frequency bands. The impairments due to the propagation of electromagnetic waves need to be evaluated accurately since system performances and sensitivity increase. The RAPIDS II software proposes a web interface addressed to both system engineers and propagation expert to calculate the effects of the troposphere, ionosphere and environment, but also the potential interferences between nearby stations. It generates statistics as well as time series for the optimization of earth-satellite systems. The user can either use the default ITU-R Recommendation models and datasets or enter his own datasets for comparison. Examples are shown to highlight the versatility of the tool.

Index Terms—Propagation; Space communication;

I. INTRODUCTION

The use of higher frequency bands offers a wider bandwidth, enabling the transmission of wideband/high data-rate multimedia channels or large amounts of earth-observation data, at the price of an increased sensitivity of the signal to propagation effects. In this configuration, a better knowledge and prediction of these effects are required to reduce the damages on the transmitted signals.

The RAPIDS II-version PASTEL web software [1] is an update of previous software [2] [3] which allows computing impairments due to the troposphere on Earth-Space communications. The purpose of this new software is, in the frame of an ESA contract, to update the ITU-R models, to add new models and to extend the effects to ionosphere and environment layers and also to include the interferences prediction between nearby stations. These calculations can be applied to several geometries of link as GEO satellites, LEO/MEO/HEO satellites, entire constellations, as well as other types of missions. This new web-software presents as default, configurable interfaces in term of effects, models, dataset for propagation expert and proposes pre-configured interfaces dedicated to system engineers.

In order to illustrate the flexibility of this new tool, the web software and its main features are firstly described. A set of results are presented as examples for the ionosphere, troposphere and interferences. The last part exposes the evolution capacity of the software in order to present the potential of new model integration.

II. SOFTWARE PRESENTATION

RAPIDS II allows registered users to log-in, via Internet, and to perform propagation calculations. The Spring Webflow framework orchestrates the sequence of steps to collect all information from the user, for the complex calculations the software needs to perform. Once a job definition is complete, the job is submitted to a SunGrid scheduler which will asynchronously send the job to the MATLAB calculation engine and track its execution. When the job is submitted, the user can do other actions, including launching new jobs or logging out. He can be notified by e-mail of the conclusion of a job. The output is in the form of statistical curves or time series for tropospheric attenuation, scintillation and environment. Output files are in HDF5, MATLAB and CSV formats.

A novelty of this version is that it is addressed to system engineers, via generic systems, as well as propagation experts. After a successful login, the user is viewing the first page where he can consult calculations stored in his own space ("My calculations") or choose a new calculation (cf. figure 1). In this case, various possibilities are proposed:

- Expert workflow
 - Effects – expert mode
- System workflows
 - Fixed terminal Telecom System
 - Mobile terminal Telecom System
 - GNSS

A. Expert user mode

The expert workflow allows the full choice of the effects, models and data, with a total of 7 different workflows:

- Ionosphere (satellite mode);

- Troposphere (satellite mode or single site mode);
- Rain fields or Tropospheric Time Series (attenuation and scintillation);
- Environment (satellite mode);
- Interferences (transmission loss or coordination area).

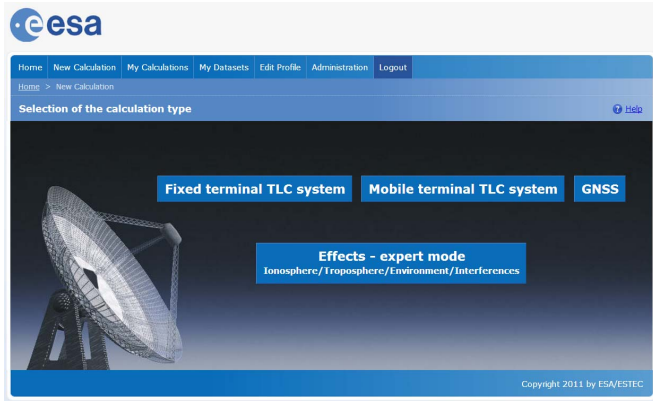


Figure 1. Web page dedicated to new calculations

The user can only run one workflow at the time. The satellite mode (in troposphere and ionosphere) proposes the choice of different kind of satellites:

- Geostationary satellites
- Non-geostationary satellites
 - LEO/MEO/HEO satellite
 - Satellites constellation
- Manual entry of elevation angles

Each user can enter and share his own satellites and payloads or choose among the available list of satellites. An orbit generator based on NORAD algorithms [4] is also included in the software for LEO/MEO/HEO satellites and the user has to enter the start date and the observation time. For the constellation, the user can enter YUMA files [5] or TLE files [6] put in “My Datasets” space. The single site mode for troposphere offers the possibility to calculate propagation effects for given elevation angles, frequencies and polarizations without having to define a satellite.

Each user can enter and share its own satellites and payloads, sites and regions or choose among a set of publicly available satellites, sites and regions. In any workflow, the user chooses the effects to compute and the models that will perform the calculation. The content of the effects selection screen presented to the expert user who has chosen tropospheric effects is presented hereafter:

- Attenuation, including Attenuation by oxygen, water vapour, clouds, rain, Scintillation; Combination of effects, Site diversity;
- Tropospheric excess delay;
- Depolarization due to rain and ice;
- Sky noise temperature;

- Dynamic effects including Fade slope, Fade duration, frequency scaling.

Complementary cumulative statistics are generated but 2D-rain fields and time series for attenuation, scintillation and environment can also be generated.

The content of the effects selection displayed to the user when the ionosphere workflow is selected is:

- Ionospheric parameter (Total Electron Content, Geomagnetic field)
- Ionospheric delay
- Tropospheric delay
- Scintillation
- Faraday rotation.

On ionospheric workflow, the calculation of ionospheric delay often used for navigation systems is completed by the tropospheric excess delay in order to avoid the user has to run twice the configuration, once for the ionospheric and once for the tropospheric excess delay only.

The list of effects proposed on the environment workflow contains:

- Building effects
- Vegetation effect
- Roughness of terrain (hill, mountains, lakes, etc)
- Mixed propagation effect
- Maritime and aeronautic effects

The interference workflows (coordination areas and transmission loss) are exception in the sense that they are not proposed on the system user workflow and each of them are composed of only one model.

For all workflows, various datasets are proposed for some of the parameters: for example pressure, temperature and humidity profiles can come from the standard atmosphere profiles, from the ESA analysis of ERA15 database, from WMO stations or from user’s database. The default input parameters are those proposed in the ITU-R models. The expert user is able to choose its own input data in the datasets presented or to enter its own dataset (stored in “My Datasets”). The help files will give detailed formats for the users who intend to enter their own datasets. Intermediate results are also available in the output file, such as atmospheric parameters calculated or extracted from databases.

B. System user mode

The system user workflows inherit the features of the expert users but in a more guided way. In fact, for each system, a limited subset of effects and models are selected by default in order to match typical configurations. The aim of the system workflows is to provide a manner to quickly parameter typical

configurations envisaged by ESA. The models selected by defaults are the ITU-R models. Thus, the choices of the user are restricted to the ground and space stations, the atmospheric layer and some input values.

For example, if the user chooses the Fixed Terminal TLC System, he selects the satellite orbit, the type of satellite coverage (Single Earth-station or Region) and the atmospheric layer (Tropospheric effects or Ionospheric effects). In very specific cases where both tropospheric and ionospheric effects are needed (for example in tropical areas around 3 GHz) the user can run the software twice, once for each layer. The advantage is that he can store its configuration in its space "My calculation" and recover the stations or region and satellite for the second run.

The tropospheric effects are limited to:

- Attenuation due to oxygen, water vapour, clouds and rain;
- Scintillation;
- Total attenuation;
- Sky noise attenuation.

The selected ionospheric effects are:

- Ionospheric parameter (Total Electron Content);
- Ionospheric delay;
- Tropospheric delay;
- Scintillation;
- Faraday rotation.

For the Mobile Terminal TLC system, three impairments are proposed: Ionospheric effects, Tropospheric effects and Environment effects. Only Environment effects and ionospheric effects are available for GNSS system. In the two last systems, pre-configured scenarios of environment are proposed as urban environment, sub-urban environment, etc. The mean position of the mobile receiver is also requested. The exact position of the mobile with respect to time is not important for statistical results.

III. TYPICAL CALCULATION

To illustrate the possibilities offered by the software, calculations of impairments coming from the ionosphere, troposphere and interferences are presented. For the ionosphere, the variation of the propagation delay across a region for future Galileo systems is shown. The troposphere examples are related to the attenuations due to water vapour. The interference result examples concern two nearby earth stations and show the evolution of loss parameters.

For each kind of configuration, results are downloadable in various formats and can be post-treated by the user with its own tools and models. The graphical results are used for a first verification but the results are also provided as matrices in HDF5, MATLAB and CSV formats for further analysis by the user.

A. Ionosphere impairment

The navigation systems require a thorough knowledge of ionosphere impact on the signal transmission. For this purpose, a set of models was developed in order to predict the performances of transmissions. The ionospheric models described on ITU-R recommendations are available on the RAPIDS II software. For the future Galileo system, specific models were developed as the Nequick for Galileo. These models are already implemented on RAPIDS II and allow evaluating the ionospheric delay (cf. figure 3).

This example of result is generated by the ESA Galileo single frequency model [7] based on the Total Electron Content computed by Nequick for Galileo model (cf. figure 2). These results are obtained through the ionosphere workflow on expert mode of RAPIDS II.

At this stage, it is important to highlight the flexibility of RAPIDS II. In fact, the ionospheric results are dependent to the date and moment of the day. Thanks to the management of the submitted jobs, it becomes easy to duplicate a specific configuration and launch a second run by just changing one parameter like the hour of the day and thus compare directly the results and the impact of this parameter.

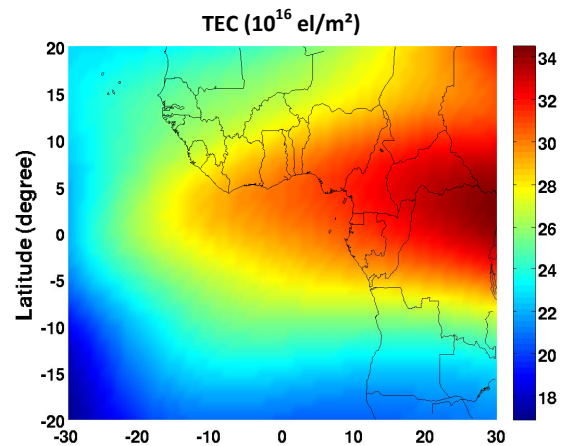


Figure 2. Total electron content computed with Nequick for Galileo model

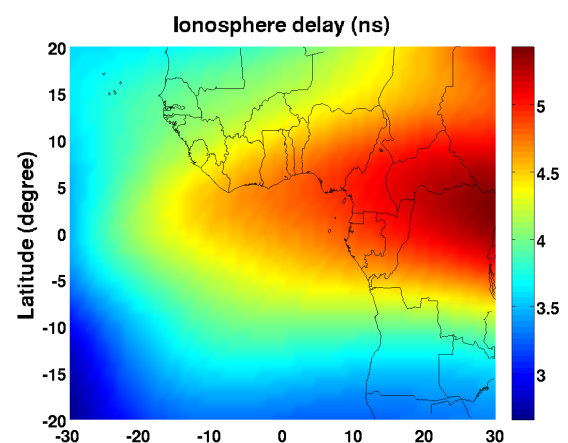


Figure 3. Delay undergone by electromagnetic waves across the ionosphere

B. Troposphere impairment

The troposphere contains the majority of the atmospheric mass and its influence prediction is essential for number of space systems.

The attenuation due to water vapour is presented in figure 4. In order to evaluate the attenuation in function of the elevation angle, the "single site" workflow is chosen for 4 different sites and the attenuation is calculated for elevation angles between 5 and 10 degrees, using the ITU-R Recommendation P.676-8 [8] general method.

Table I presents intermediate results computed from ITU-R P.835-4 Recommendation [9], used for the calculation of the water vapour attenuation. These values are determined by default by the ITU standard atmospheres but the user can extract them from ECWMF ERA15 database or even enter his own datasets.

Figure 5 represents the attenuation due to water vapour applied on the Europe continent, using the ITU-R P.676-8, general method.

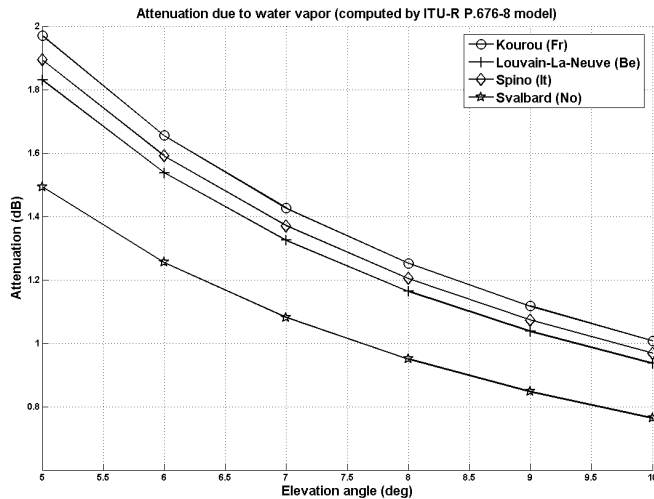


Figure 4. Attenuation due to water vapour, ITU-R P.676-8, general method

TABLE I. EARTH STATION ATMOSPHERIC PARAMETERS AT THE GROUND LEVEL

Name	Pressure (hPa)	Temperature (K)	Humidity (%)
Kourou	1011.35	288.052	7.44
Louvain	996.024	287.217	6.98
Spino	1003.1	287.6	7.19
Svalbard	954.51	284.9	5.84

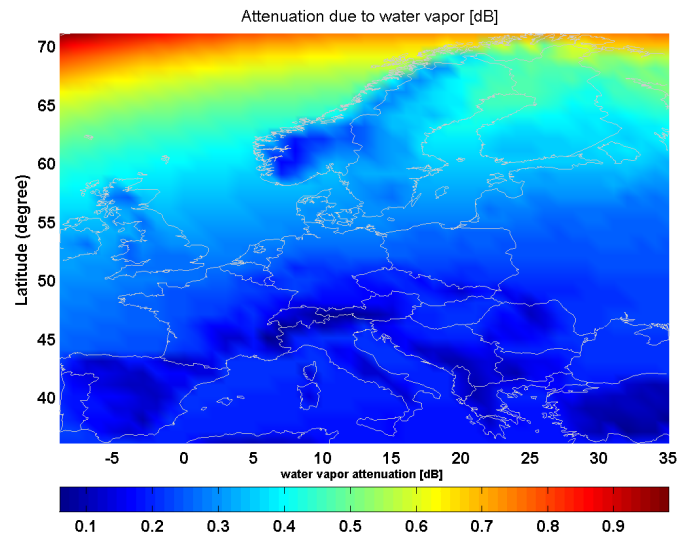


Figure 5. Attenuation due to water vapour, ITU-R P.676-8, general method

C. Interference impairment

The multiplication of space applications and the limitation of the radio spectrum increase the potential interferences between earth stations. The coordination areas aim to detect the potential interferers around an earth station while the transmission loss evaluation predicts more accurately the interference between two specific earth stations. The ITU-R P.452-14 [10] recommendation is dedicated to this effect and describes a model able to compute the transmission loss parameter.

The possible interferences can come from clear air propagation mechanism (terrain reflection or diffraction, ducting, etc.) and/or be generated by rain scattering. Worst month or average year can be chosen for the statistics. The figure 6 presents, for two nearby earth stations, the propagation loss evolving with percentage of time. This figure is dedicated to interferences due to clear air propagation while the figure 7 shows the transmission loss evolution from rain scattering.

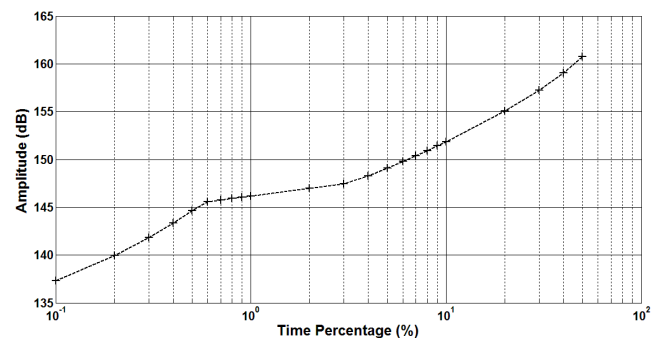


Figure 6. Propagation Loss from an interfering transmitter to the interfered-with receiver due to clear air propagation.

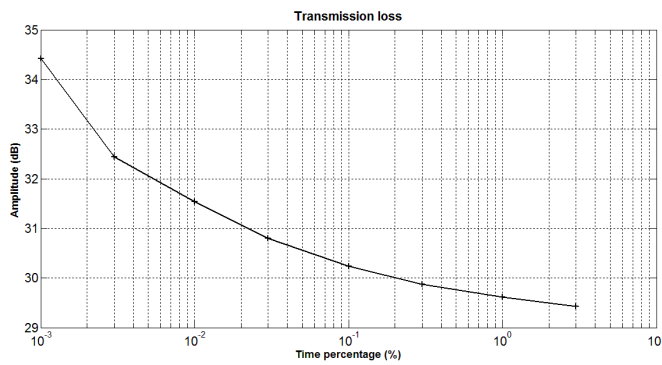


Figure 7. Interference (Transmission loss parameter) between two stations generated by rain scattering.

IV. EVOLUTION OF THE SOFTWARE

RAPIDSII is foreseen to enable the introduction of new datasets and new models. The new dataset can be tested by users, users groups and administrator via “My datasets”, and can then be introduced in the software by the administrator. Upgraded models can be introduced easily if they use the same input and output parameters as the previous model (for example new versions of ITU-R recommendations).

If updated or new models require new inputs or generate new output, changes in the workflows are possible but require a development effort. Each model is considered as an additional module to the general RAPIDS II structure. New inputs may generate:

- Web pages (html, xml templates and images)
- Help files (html, xml templates and images)
- Models compiled for the target server OS
- Datasets
- Configuration file (new or updated of existing files)

Modifications in a workflow necessitate upgrades in all the above mentioned files. A workflow configuration will always contain version information:

- Current version of the workflow
- Compatible version for which a saved calculation can be reused as default value for this workflow.

V. CONCLUSION

The RAPIDS II software is a new web tool for propagation calculation. It will replace the current version by updating the ITU-R models involved and adding new models for the troposphere effects. It also extends the field of investigation by including ionospheric, environmental and interference effects.

This software is useful for propagation expert but it also aims to facilitate the access to propagation prediction to users not familiar with propagation models by dedicating pre-configured web pages to classical transmission systems.

The flexibility of RAPIDS II software is demonstrated by the large amount of choices allowed to the different users. Several link geometries are available including geostationary and non-geostationary satellites, constellations or even manual elevation angle values. The coverage of these satellites varies from single earth station to an entire region and these choices are applicable to all atmosphere layers. The inputs and datasets are also customizable by allowing users to enter their own values and files.

Thanks to all these features, system users can quickly evaluate link budget parameters while expert users can evaluate specific configurations or compare the models or datasets between them.

The software structure is also built with the purpose to be updated easily allowing RAPIDS developers to include quickly updates of the program and add new models in the limit of the current inputs and outputs.

Finally, the RAPIDS II software development is still ongoing but the release date is foreseen in 2013 for an ESA delivery which will distribute accounts to users.

REFERENCES

- [1] Vanhoenacker-Janvier D., Pereira C., Segart B., Lechien L., Cheffena M., Castanet L., Martellucci A., RAPIDS II version PASTEL: a new propagation analysis tool for design of fixed and mobile systems, ESA Workshop on Radiowave Propagation, ESA, Noordwijk, 30/11-2/12/2011.
- [2] Rogister A., Fisset R., Vanhoenacker-Janvier D., Vasseur H., Salonen E., Poiars-Baptista, RAPIDS, an innovative database application for radio propagation prediction, Proceedings of the 8th URSI Com. F. Triennial Symposium, Sept. 1998, Aveiro, pp. 20-23.
- [3] <http://saruman.estec.esa.nl/rapids/app>
- [4] David A. Vallado, Paul Crawford, Richard Hujsak, and T. S. Kelso. Revisiting spacetrack report #3. In AIAA Astrodynamics Specialists Conference and Exhibit, August 2006, 2006.
- [5] <http://www.navcen.uscg.gov/?pageName=gpsAlmanacs>
- [6] <http://www.celestrak.com/NORAD/elements/>
- [7] ARBESSER-RASTBURG, B. (2006): *The GALILEO single frequency ionospheric correction algorithm*, (3rd European Space Weather Week, Brussels).
- [8] Recommendation ITU-R P.676-9, Tropospheric attenuation by atmospheric gases, February 2012
- [9] Recommendation ITU-R P.835-4, Reference standard atmospheres, 2005.
- [10] Recommendation ITU-R P.452-14, Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz, October 2009