Channel modelling activities related to atmospheric effects in the SatNEx project

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***Abstract*— This paper presents a summary of the activity carried out in the framework of the second Focus Topic "Atmospheric effects" of the Joint Activity JA-2310 "Channel modelling and propagation impairment simulation" of the European Network of Excellence SatNEx.**

I. INTRODUCTION

Optimization of satellite systems requires taking into account propagation information early in system design. Indeed, whatever the considered application (fixed, mobile, HAPS, navigation or broadband systems), the propagation channel has a strong impact on system performances and relevant channel models are necessary to assess by simulation the end-to-end quality of service and the satellite system performances. The Joint activity JA-2310 "Channel Modelling and Propagation Impairment Simulation" of the Network of Excellence SatNEx [1] is dedicated to the investigations of all issues related to propagation for satellite communications and navigation. Taking into account the specific characteristics of their related environment, the fields of investigation of JA-2310 are divided into 4 Focus Topics : "Mobile/indoor multipath" [2], "Atmospheric effects" (this paper), "Wireless Optics" [3] and "Satellite navigation channel" [4]. In this paper, the activity related to the second Focus Topic, Atmospheric effects, is presented.

For what concerns FT-2312 "Atmospheric effects", a first series of models has been proposed in a first phase of SatNEx to take into account the influence of the propagation channel, both in terms of temporal variability thanks to the development of time series synthesisers, and in terms of spatial correlations thanks to the development of rain attenuation field generators [5]. In the second phase of SatNEx, the activity aims at going further in the modelling of the propagation channel specifically to answer the needs of adaptive systems. To reach this objective, four single research activities have been defined: Time series synthesis, Multi-channel modelling, Channel assessment techniques for Fade Mitigation Techniques and Radiowave propagation in tropical and equatorial areas.

II. TIME SERIES SYNTHESIS

The objective of the first activity is to develop and test new time series synthesisers. Particular attention is given to the assessment of their input parameters and to new comparisons with propagation data. Examples of channel models studied in this activity are enhanced version of the Maseng-Bakken model [6] [7] [8] [9] or N-states Markov models.

A first enhanced version of the Maseng-Baken model consist in adding an offset parameter to the model (Figure 1) to be more representative of the propagation channel dynamics [5].

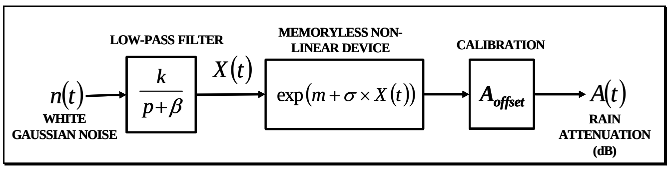

Figure 1: Principle of the Enhanced Maseng-Bakken Model

A second enhanced version of the Maseng-Baken model, the Lacoste-Carrie model, allows to control the generated attenuation events by introducing maximum attenuation, total duration and the position of the maximum attenuation.

Using data collected in different areas in temperate climates, the input parameters of the model have been retrieved for different frequencies, elevations (as well as for terrestrial links) and climatic conditions.

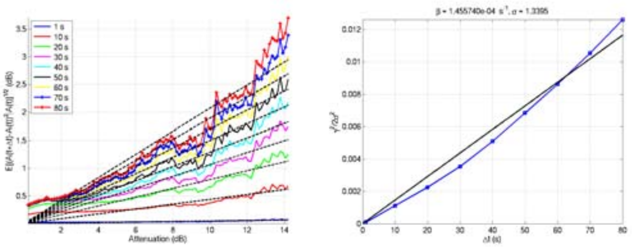

Figure 2: retrieval of the beta parameter with respect to terrestrial measurements at 23 GHz in Budapest

Then, in a following step, the models have been tested with respect to beacon data collected essentially during OLYMPUS and ITALSAT propagation experiments. These tests have been performed with respect to conventional statistics (fade slope, fade duration), and using the Mahalanobis metric [5].

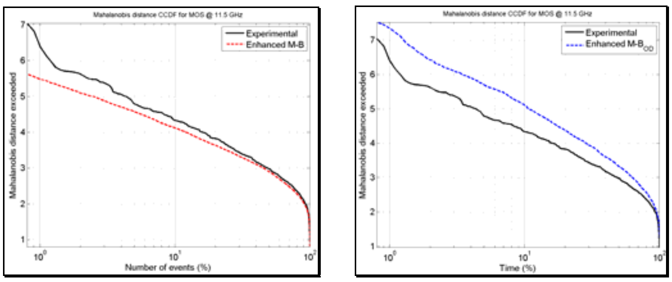

Figure 3: Test of the Enhanced Maseng-Baken model (left) and of the Lacoste-Carrie "on-demand" model (right) with respect to experimental data collected in Mosqueiro, near Belén (Brazil)

The developed time discrete irreducible N-state Markov chain model (Figure 4) can be applied for generating rain attenuation time series regarding to terrestrial microwave links from 15 GHz up to 38 GHz frequency with horizontal or vertical linear polarization and for estimating the first order statistics of attenuation on a proposed link already in the planning phase [11]. The model includes numerous discrete states; each state represents an attenuation level with 0.05 dB resolution.

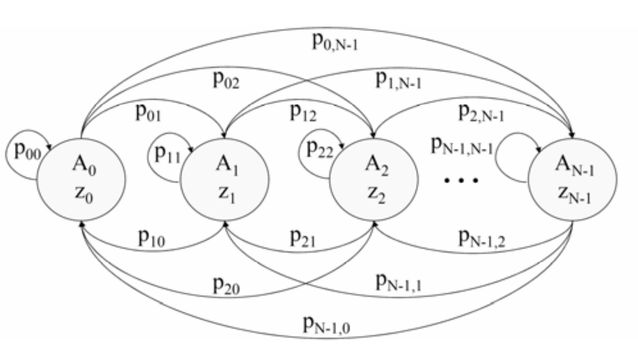

Figure 4: Block diagram of a N-state Markov chain model

The model parameters were retrieved considering several attenuation data series, which were measured on different terrestrial microwave links. The transition probability parameters of the N-state Markov model are calculated with fade slope statistics. First the conditional probability density function of fade slope is estimated with simple Gaussian distribution function at each attenuation level. The transition probabilities are finally calculated from the Gaussian fade slope distributions.

Estimating rain attenuation regarding to a proposed link the model parameters must be first transformed in order to get time series for the appropriate link [11].

III. Multi-channel modelling

The aim of this second single research activity is the development of Multi-dimensional channel models. Applications are linked either to space-time rain attenuation generation and/or to real-time prediction. This research activity is related to the outcome of Radio Resource Management and to the need to get space time correlated time series to dimension to emulate and dimension those systems.

As this activity is relatively recent with regards to the development of time series synthetizers, different characterizations of the spatial or spatiotemporal properties of attenuation have been undertaken in a first phase. Most of those characterizations ([12],[13]) have been carried out on weather radar data since the available propagation measurements are not sufficient .

In the framework of this activity, the temporal evolution of the rain cells extracted from the Spino d'Adda radar dataset has been investigated with the aim of providing preliminary results about the tem poral dynamic of the rainfall process that could be useful for devising new space-time rainfall models based on cellular approachs (e.g. the MultiEXCELL model). It also accounts for the spatial organization of the rain cells as illustrated on Figure 5.

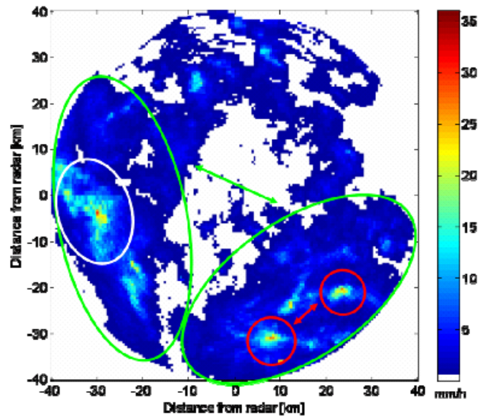

Figure 5: space-time stochastic modelling of rainfall rate over Europe using inputs from the ERA40 ECMWF database (right)

The temporal evolution of the cell's area and intensity has been analyzed and modelled both separately and jointly.

Whilst the former analysis is rather simple, the latter is more interesting as it revealed that rain cells, when modelled by means of their EXCELL equivalent parameters (R_M = peak rain intensity and ρ_0 = effective radius) [15], evolve in time according to an advection-diffusion scheme [16], such that when the peak intensity increases, the dimension of the cell decreases and vice versa. Figure 6 shows the relationship between the R_M and ρ_0 values for 742 rain cells evolving in time (each colour corresponds to one rain cell "story").

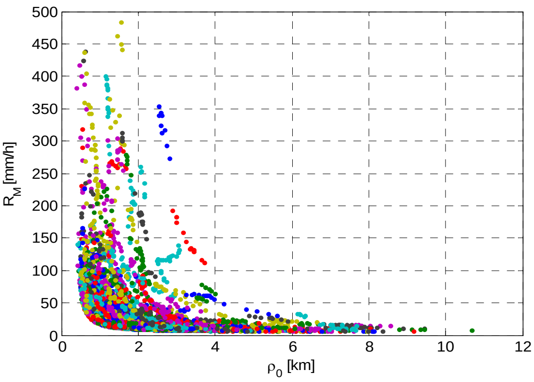

Figure 6: Joint evolution of R_M and ρ_0 for all the 742 tracked cells extracted from the Spino d'Adda radar dataset

An other methodology, that extends previous works described in [18] and [19] is developed in [17]. It aims at generating over a continental satellite attenuation field correlated in space and in time as illustrated at Figure 7 modelling rain fields as space-time correlated random fields. The stochastic modelling is constrained by the ECMWF (European Centre for Medium-Range Weather Forecast) ERA-40 rain amount and wind database.

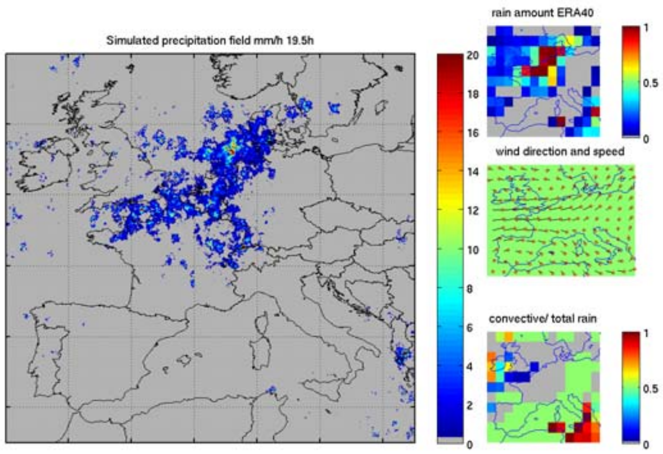

Figure 7: space-time stochastic modelling of rainfall rate over Europe using inputs from the ERA40 ECMWF database (right)

Lastly in order to obtain estimation an estimation of the attenuation at short term a combination of ECMWF forecast data, of MeteoSat (MSG) brightness temperature (Figure 8) and of the EXCELL models is proposed in [20].

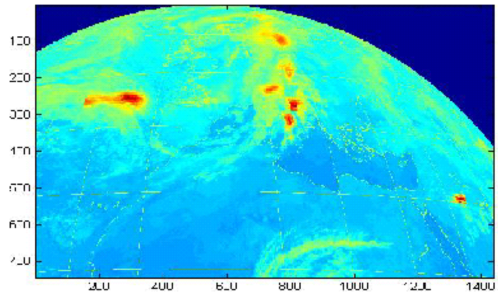

Figure 8: Composite image resulting from an ECMWF map of total precipitation accumulated during a 6 hours time interval and the concurrent MSG picture of cloud coverage

IV. Channel Assessment Techniques for Fade Mitigation Techniques

In the third single research activity (Channel assessment techniques for Fade Mitigation Techniques), prediction models are studied to assess the performances of FMT such as Site Diversity.

The Site Diversity technique consists in the duplication of the main ground station few kms apart by exploiting the spatially limited extension of precipitation (the most intense convective rain cells hardly exceedes few kms), which represents the main tropospheric effects.

In the past several propagation experiments have measured the single site and joint cdf of rain attenuation and most results have been collected in the ITU—R dbsg3 database, which has been completed during SatNEx activity by adding statistics from Olympus experiments in Italy.

Moreover several models published in the literature predict the site diversity gain (representing the attenuation margin reduction possible withthe site diversity system) or advantage (representing the reduction in the outage probability possible with the site diversity system). The models have been reviewed and software implemented.

In a first step, site diversity models have been tested against the DBSG3 experimental database (Figure 10). The best results have been obtained with the Paraboni-Barbaliscia model [15], leading to its approval in Rec. ITU-R P.618-9.

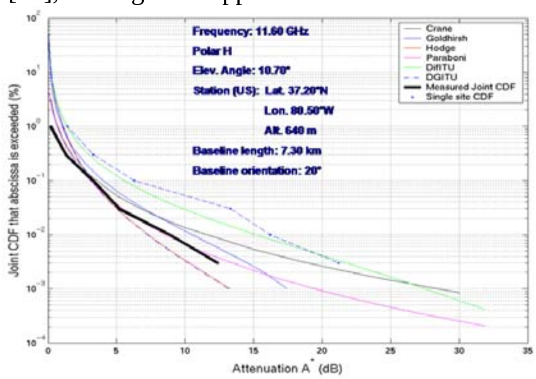

Figure 9: Comparison of Site diversity prediction methods

One of the main problems in the performance evaluation of site diversity models consists in the limited characteristics (baseline distance and orientation) of the set of measured statistics. It is possible to overcome this limit by using radar simulation, i.e. by calculating attenuation experienced on different radio links placed on the rain intensity maps derived from radar measurements. With this approach, it is so possible to simulate site diversity systems with different baseline distance and orientation and to derive statistics of gain as a function of the distance (see Figure 10).

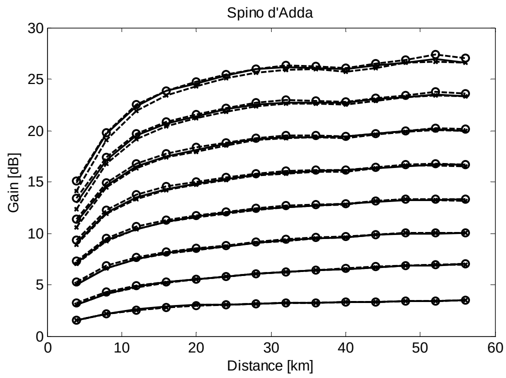

Figure 10: Site diversity statistics derived from radar data measured in Spino d'Adda, Italy

Rain attenuation may show significant differences even within a relatively small area, e.g. in case of converging terrestrial radio links. The size, translation speed and direction of rain cells are determined by the local environment. The parameters of the individual rain cells, like dimension, rainfall rate and the occurrence probability can be modelled with an exponential rain cell model, whilst the translation with a Markov-chain based random walk [16]. The method is applicable to predict the annual attenuation distribution of converging links and express the differences among them; therefore it is also suitable for diversity calculations. A similar model for terrestrial-satellite diversity can be also foreseen.

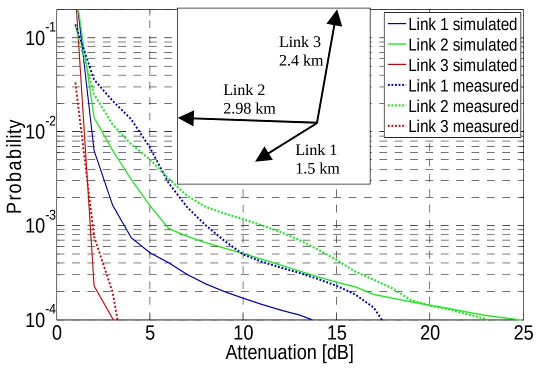

Figure 11: Rain attenuation prediction for converged links in Budapest

V. Propagation in Tropical and Equatorial Areas

The objective of the fourth single research activity is to study/model radiowave propagation in tropical and equatorial areas and in particular over the Amazon region in Brazil.

Using Recommendation ITU-R P.618-9 the CDF of atmospheric impairment in Manaus whas been generated at Ka-band uplink frequency. The various components of the atmospheric impairment namely scintillation, gas, clouds and rain attenuation, are explicitly shown in Figure 12. The total impairment is the combination, as specified in the recommendations, of all the individual components.

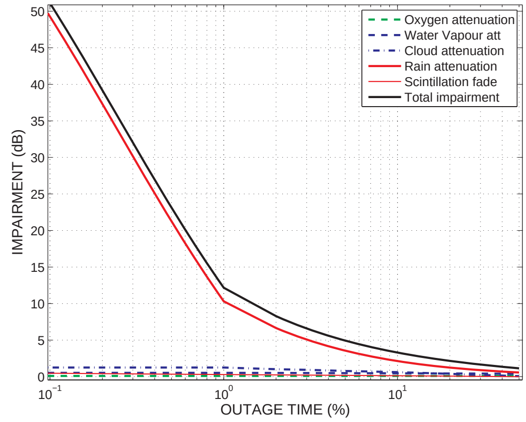

Figure 12: Atmospheric Impairment CDF for Manaus (-3.1, -60.01) at Ka band (30 GHz)

On the other hand, a novel stochastic dynamic model for the prediction of rain attenuation dynamic properties (spectral density function, fade durations) of fixed satellite slant paths operating above 10 GHz and locating at heavy rain climatic regions, has been proposed (see Figure 13 and Figure 14).

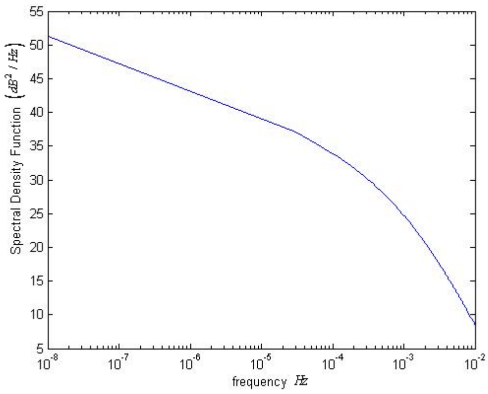

Figure 13: Theoretical Spectral Density Function of slant path rain attenuation, at Tabatinga, Brazil at Ku band

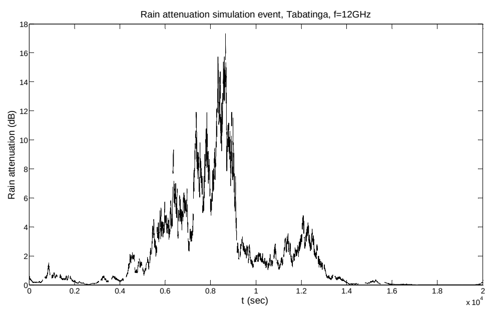

Figure 14: Simulated rain attenuation time series at Tabatinga, Brazil, at Ku band

VI. Conclusion

In this paper the main results of the activity devoted to atmospheric effects in the framework of SatNEx JA-2310 (Channel modelling and propagation impairment simulation) have been summarized. This activity has been focused on time series synthesis, multi-channel modelling, channel assessment techniques for FMT, and radiowave propagation in tropical and equatorial areas.

Typical outputs of the project include: articles to journals, conference papers, tutorials, a special issue in Journals such as International Journal of Satellite Communications & Networking, contributions to standardization bodies and in particular contributions to ITU-R Study Group 3.

New European projects have been labelled partly thanks to SatNEx JA2310 such as the New COST action IC-0802 labelled last June 2008: Propagation tools and data for integrated Telecommunication, Navigation and Earth Observation systems or a Clustering activity with the FP6 BRAZIL project, called Tabatinga.

SatNEx activities resulted into new versions of ITU-R Study Group 3 such as: Rec. ITU-R P.837-5 (mapping of precipitation and rain rate prediction), Rec. ITU-R P.618-9 & P.1815 (site diversity & differential attenuation). Work are still in progress to improve: Rec. ITU-R P.836 and P.840 (water vapour and cloud attenuation), Rec. ITU-R P.618 (rain attenuation and time diversity modelling) and to propose a new Recommendation on time series synthesis.

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