Attenuation Time Series Synthesizer for Dynamic Prediction in Millimeter Wave Frequency Bands

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***Abstract*—Radio communication systems using millimeter wave (mmWave) are not only an essential component in the fixed traditional services, but also a key element which is highly needed in future 5G radio access mobile networks. Although hydrometeors attenuation is the most influential factor related to the total propagation losses at frequencies above 10 GHz, increasing rapidly at higher frequencies, several additional effects should not be ignored in the design of mmWare communication systems. The aim of this work is to generate a time series that reproduces the spectral characteristics of propagation impairment events. The performance of the developed time series method for propagation channel is checked against satellite beacon measurements.**

***Index Terms*—millimeter wave communication, prediction models, fifth generation (5G), beacon satellite measurements, statistical analysis**

I. Introduction

Millimeter wave fixed links have been used for terrestrial and satellite communication systems for decades, ranging from 30 to 300 GHz, and leading to spectral congestion of the conventional frequency bands. Frequency bands of Ku (12/14GHz), Ka (20/30GHz), and V (40/50GHz) have been assigned to point to point systems. [1]

Mobile communications systems have so far operated in bands below 6 GHz. However, the fifth-generation, 5G, utilizes higher frequency bands, achieving more efficient frequency resources and high bit rate.

Bands above 6 GHz have been allocated to mobile services at world radio communication conference WRC-15, [2], to be used by 5G radio access networks.

3GPP Release 15 has also defined 5G operating bands and channel bandwidths. These frequency bands in which NR (New Radio) can operate, are designated for different Frequency Ranges (FR): FR1 and FR2. Table I shows the corresponding frequency range for each FR. [3]

TABLE I. 3GPP Release 15 Frequency Ranges

Frequency Range Designation	Corresponding Frequency Range
FR 1	450 MHz – 6000 MHz
FR2	24250 MHz – 52600 MHz

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World Radiocommunication Conference, WRC-19, has included these frequency bands as candidates to be 5G Spectrum. [4]

- 24.25–27.5 GHz
- 31.8–33.4 GHz
- 37–40.5 GHz
- 40.5–42.5 GHz
- 42.5–43.5 GHz
- 45.5–47 GHz
- 47–47.2 GHz
- 47.2–50.2 GHz
- 50.4–52.6 GHz
- 66–76 GHz
- 81–86 GHz

According to the theory of radio wave propagation, mmWave frequencies are sensitive to tropospheric physical phenomena. Total impairments to signal depends on rain, clouds, oxygen and water vapor gas molecules and other factors in the Earth's atmosphere. Specifically, hydrometeors are one of the most dominant factors for terrestrial and satellite communication systems link performance.

Simulation and prediction of time dynamics of the propagation channel may be required for a proper planning of terrestrial and Earth-space systems, fixed and mobile. The target of rain dynamics analysis is to improve the efficiency of several techniques that are used to reduce the final attenuation, such as adaptive coding and modulation or adaptive power control.

Numerous studies have focused on time series synthesis. [5]-[7]

Recommendation ITU-R P.1853-1 provides detailed information on how to generate rain attenuation time-series. [8]

This paper presents a prediction method for the synthesis of the time series of propagation channel for terrestrial or Earth-space paths, based on stochastic differential equations currently in the literature. Rain attenuation model is based on a modified version of the Maseng-Bakken model. It consists of an Auto Regressive model of order one.

Simultaneous generation of scintillations and attenuation by gases and clouds are additionally provided.

This model is tested in different environments and conditions. Moreover the performance of the method is checked against satellite beacon measurements. In

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addition, local meteorological measurements are included in the comparison.

II. Time Series Synthesizer

Implemented computer tool, based on Recommendation ITU-R P.1853-1, synthesizes total attenuation time series combining the effects produced by propagation mechanisms of rain, clouds, oxygen and water vapor molecules, and scintillation due to non-homogeneity of the index of refraction in the atmosphere.

Total attenuation time series synthesized, A(kTs), is computed as:

$$A(kT_s) = A_R(kT_s) + A_C(kT_s) + A_V(kT_s) + A_O + Sci(kT_s) \quad (1)$$

where:

- $A_R(kT_s)$ is the rain attenuation time series.
- $A_C(kT_s)$, the cloud attenuation time series.
- $A_V(kT_s)$, the water vapor attenuation time series.
- A_O, the mean annual oxygen attenuation.
- $Sci(kT_s)$, the scintillation time series.

Discrete white Gaussian noise process, $n(t)$, is used as an input source for generation of all individual time series. Computation tool has been implemented in Matlab language.

Rain attenuation synthesis method synthesizes rain attenuation time series, $A_R(t)$, from the discrete white Gaussian noise process, n(t), assuming that long-term statistics of rain attenuation is a log normal distribution.

White Gaussian noise, n(t), is low-pass filtered taking into account the probability of rain, p, transformed from a normal distribution to a log-normal distribution in a memoryless non-linearity device, and calibrated to match the desired rain attenuation statistics.

Parameters of log-normal rain attenuation distribution (standard deviation, σ, and mean value, m) are obtained from local long-term statistical studies of rain rates measured data. In case of non-availability of local studies, rain attenuation prediction methods and global parameters established in ITU-R Recommendations can be used. [9], [10]

Cloud attenuation time series synthesis method approximates statistics of the long-term integrated liquid water content (ILWC) by a log-normal distribution. Liquid content time series, L(t), is synthesized from the discrete white Gaussian noise process, n(t). The white Gaussian noise is low-pass filtered, truncated to match the desired cloud probability of occurrence, and transformed from a truncated normal distribution to a conditioned log-normal distribution in a memoryless non-linearity device. Generated time series reproduce the spectral characteristics, rate of change and duration statistics of cloud liquid content events.

Water vapor attenuation time series synthesis method assumes that long-term statistics of Integrated Water Vapor Content (IWVC) is a Weibull distribution. These IWVC distributions are well-approximated by a Weibull distribution over the most significant range of exceedance probabilities. The water vapor content time series, V(t), is synthesized from the discrete white Gaussian noise process, n(t). The white Gaussian noise is low-pass filtered and transformed from a normal distribution to a Weibull distribution in a memoryless non-linearity.

Scintillation time series is generated by filtering white Gaussian noise, n(t), such that the asymptotic power spectrum of the filtered time series has an f–8/3 roll-off and a cut off frequency, fc, of 0.1 Hz. The standard deviation of the scintillation increases as the rain attenuation increases.

Mean annual oxygen attenuation A_O is converted from the mean annual temperature, T_m, following the method recommended in Recommendation ITU-R P.676. Mean annual temperature T_m, is computed using experimental values if available. [11]

III. Methodology

In this project, a methodology of procedures has been developed to evaluate the performance of time series synthesizer. Evaluation of synthesizer performance is based on a statistical analysis compared between experimental and simulated series. Schematic summary of the used methodology is showed on Fig. 1.

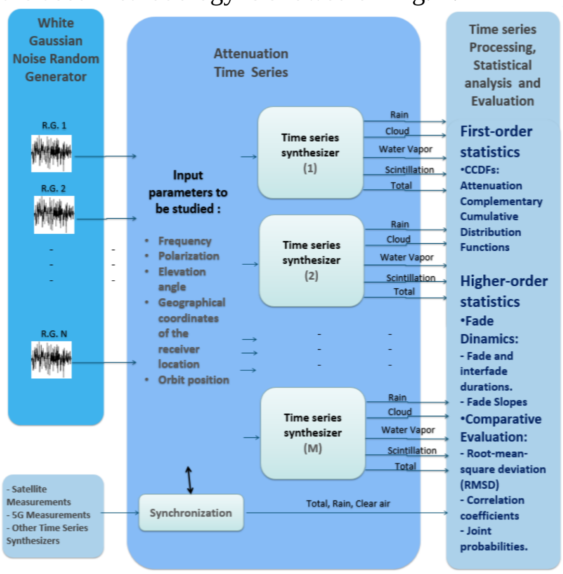


Figure 1. Overview of the used methodology.

Experimental attenuation time series have been obtained both from satellite and land mobile measurements.

Satellite signal measurements data have been obtained with a Ka beacon signal receiver continuously recording for a full year, from October 2014 to October 2015, and a sampling rate of 8 Hz. Activities for generation, processing and verification of correct implementation of all system equipments functionalities have been carried out in this time period.

One month attenuation time series have also been used from measurements made on a link between a fixed transmitter and mobile receivers at frequency of 25 GHz, during May 2019. Receivers are located in Bilbao, Spain.

The main step to generate experimental time series involves the identification of rainy conditions utilizing information from ancillary equipments. Samples of time series for total attenuation are classified in terms of the meteorological characteristics of the slant path according to three types: Rainy, Overcast and Clear sky periods.

In parallel, a pre-processing of the raw data is carried out in order to debug the baseline data for the later statistical study: bias removal, identification of measurement outliers, data flagging and parameter extraction and assimilation of measurements. As a result of this process we obtain the definitive attenuation time series of rainfall events.

Instantaneous attenuation has later been calculated as the difference between the mean level in the absence of rain and the signal received level at that time.

Several time series prediction simulations have been performed, modifying input parameters in the synthesizer. The study of parameters that describe the evolution of attenuation in dynamic and long-term time is especially important.

We have selected the parameters listed below:

- Frequency. The distribution of excess attenuation at one frequency conditioned at the excess attenuation at another frequency is of interest to this study.
- Elevation angle for a given geographical location. Statistical parameters of rain attenuation are strongly dependent on slant path.
- Time scales. In order to analyze event and intra event levels.
- Volume of needed processed samples.

Additionally we have simulated times series for different parameters describing the time evolution of rain attenuation, and parameters depending on the site as geographical location and local climatic characteristics.

In order to carry out the comparative statistical study of the dynamic characteristics, joint series processing software has been developed. They process joint series derived from synthesizer and experimental measurements.

Software procedures are created in MATLAB. They include calculation and graphical representation of first order (Attenuation Complementary Cumulative Distribution Functions, CCDF) and second order statistics (CCDF of Fade durations and slopes)

Software for comparative and evaluation of time series includes calculations such as Root mean square deviation, correlation coefficients or Joint probabilities between series.

Results are registered in graphics and tables in order to be subsequently processed to evaluate the sensibility of the time series synthesis method and to test some degree of correlation between fading mechanisms of the propagation channel.

IV. Results and Conclusions

Following figures show results from the implemented synthesizer and statistical comparison with experimental measurements in the location of Bilbao, Spain.

Fig. 2 depicts yearly simulated time series of rain attenuation at the Ka Band receiver site, derived from implemented computer tool, and taking into account experimental data recorded in the study.

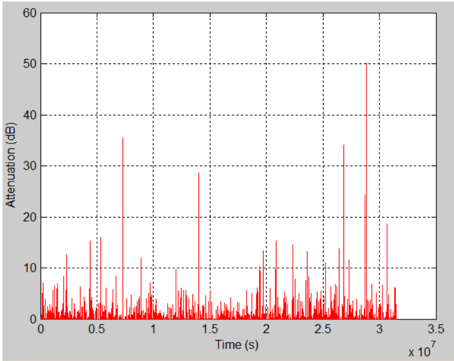
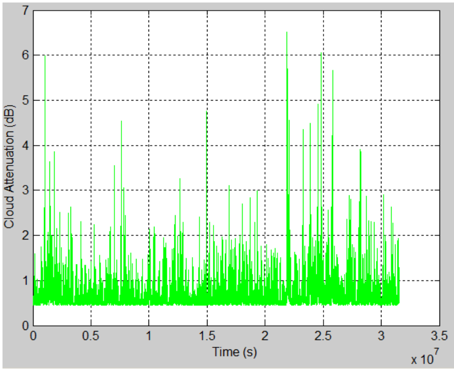
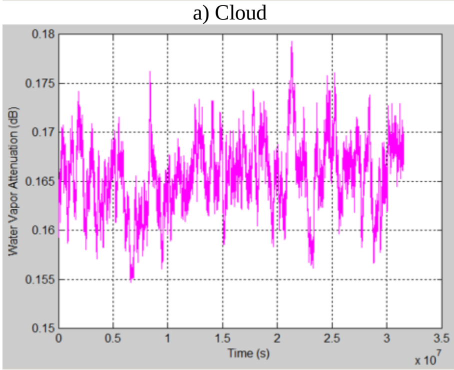


Figure 2. Yearly time series of rain attenuation simulated at the receiver site.

Fig. 3 shows time series of attenuation due to clouds, scintillation and water vapor, simulated for the same environment conditions and the same period of time.



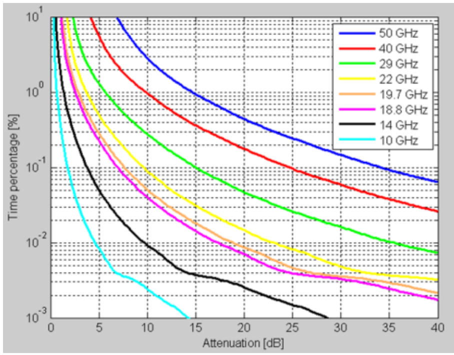
a) Cloud



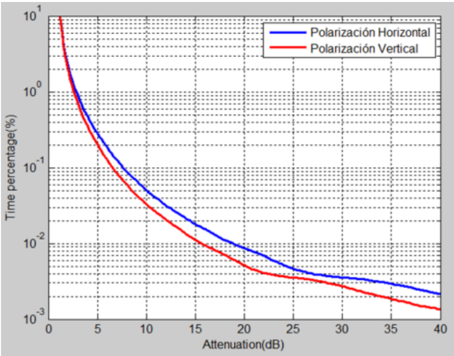
b) Water vapor

Figure 3. Simulated yearly time series, due to clouds and water vapor.

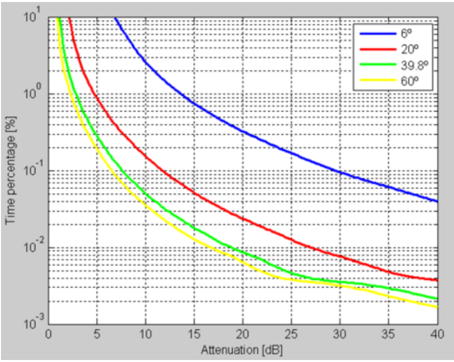
Fig. 4 shows the cumulative distribution (CCDFs) of total attenuation as function of input parameters: frequencies between 10 and 50 GHz, polarization vertical and horizontal and elevation angle between 6 °and 60 °.



a) Frequency



b) Polarization



c) Elevation angle

Figure 4. CCDF of total attenuation from Synthesizer as a function of frequency, polarization and elevation angle.

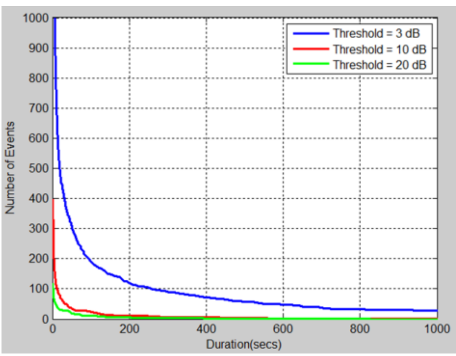
For each value of the studied parameter, percentage of time in which total attenuation exceeds attenuation value of the abscissa is represented.

From the previous figure it can be deduced that attenuation is strongly sensitive with frequency. Thus the percentage of time in which 10 dB attenuation is exceeded, varies from 0.0015% to 0.085% and 1.9% of total annual time, when frequency varies between 10 GHz, 22 GHz and 50 GHz respectively.

Dependence between attenuation and elevation angle can also be observed. For example, attenuation exceeded during 1% of the yearly time, goes from 4.5 dB for 20 º inclination angle to 14 dB with an elevation angle of 6 º.

With regard to variation of attenuation with polarization, an increase of a few decibels can be observed when changing from vertical to horizontal polarization, for practically any percentage of time.

Fig. 5 depicts fade duration statistics, that characterize the time interval between two fades, or interfade duration, for rain and total attenuation.



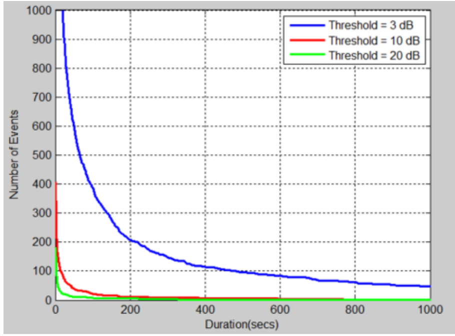


Figure 5. Distribution of fade durations and number of fades conditioned to attenuation.

Fig. 6 plots fade slope statistics of the received signal as a function of different attenuation thresholds in rainy events and total attenuation.

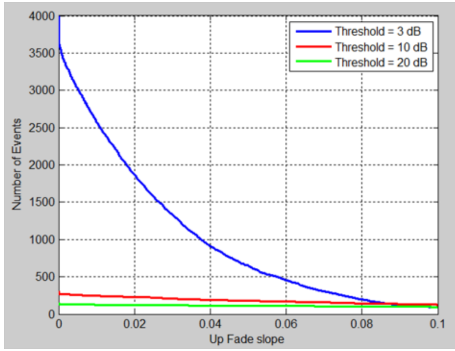


Figure 6. Distribution of fade slope and number of fades conditioned to attenuation.

It can be deduced that distribution of number of fading events with certain duration, is exclusively due to rain attenuation, when fading threshold is 10 and 15 dB. While correlation between rain and total attenuation does not exist, for thresholds less than 3 dB. In this case, total attenuation is much more dependent on the fading statistics due to the scintillation.

V. Conclusions

The implemented time series synthesis method generates a time series that properly reproduces the spectral characteristics, fade slope and fade duration statistics of total attenuation events. The long-term distributions of attenuation and duration of events maintains a great similarity between measured and simulated values, as long as the statistical parameters of the simulation are adjusted to a log-normal distribution with the same mean and standard deviation values as the experimental distribution.

Nevertheless magnitudes that characterize attenuation dynamics present a lower degree of correlation, especially in links with mobility. Indeed time series synthesizer needs many samples to produce reliable outputs. It is clear that the short-term signal dynamics is not very well characterized from the synthesizer information. A synthesizer oriented to the statistical characterization of the rain fading as the one used in this work, is not probably the most adequate solution to define the short term dynamics of the rain attenuation in mobile links. To do this, other models based on learning and training on time series should be used.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

All authors had jointly participated in all phases of this article, having approved the final version.

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