Generator of Time Series of Rain Attenuation: Results of Parameter Extraction

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Abstract. *Rain attenuation has a significant impact on the availability of millimeter wave communication systems. In order to dynamically simulate such radio systems, several generators of artificial time series of rain attenuation have been developed. This paper briefly describes the DLR channel model and presents the results of model parameter extraction from time series measured on terrestrial microwave paths in the Czech Republic.*

Keywords

Microwave communication, propagation, millimeter wave, rain attenuation, channel model.

1. Introduction

Rain fading events may cause severe outages in millimeter wave communication systems. Different fade mitigation techniques are being developed in order to overcome such propagation impairments. Recently, several time series generators have been developed [1], [2]. They produce artificial time series of rain attenuation for the purpose to simulate fade mitigation techniques under realistic channel conditions. Apparently, the generated time series should be similar to the measured ones in terms of their statistical and dynamical characteristics.

In this paper, the DLR channel model [3], [4] is briefly described. So far the DLR channel model has been applied successfully to satellite microwave paths which are subject to rain fading. In this paper, the DLR channel model is applied to three terrestrial microwave paths in the Czech Republic.

2. DLR Channel Model

The DLR channel model is based on a mix of a 2nd order Markov chain and Gaussian random variables. These define transition probabilities of the Markov chain.

The generated time-discrete time series of attenuation is denoted by $y_i = y(iT_s)$, where $i = 1,2,\ldots$ and $1/T_s$ is the sampling rate. T_s is typically in the order of 1 minute. The next value of attenuation y_{i+1} is obtained as the outcome of a single experiment of a Gaussian random variable n_i with distribution $N(\mu_i,\sigma_i^2)$, see Fig. 1.

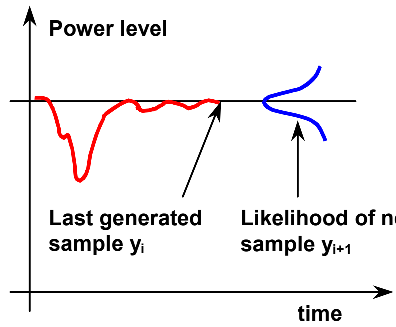

Fig. 1. Principle of generating subsequent samples of an artificial rain attenuation time series with the DLR channel model.

The parameters μ_i, σ_i depend on the previous value of the chain y_i as well as on the attenuation trend described by a segment type s_i:

$$\begin{aligned} & y_{i+1} = n_i \\ & n_i = \mathrm{N}\left(\mu_i,\sigma_i^{\,2}\right),\quad \mu_i = \mu\left(y_i,s_i\right),\ \sigma_i = \sigma\left(y_i,s_i\right) \\ & s_i = \Lambda\left(y_i - y_{i-K}\right),\quad \Lambda(x) = \begin{pmatrix} D \text{ for } x > 1\,\mathrm{dB} \\ C \text{ for } |x| \le 1\,\mathrm{dB} \\ U \text{ for } x < -1\,\mathrm{dB} \end{pmatrix} \end{aligned} \tag{1}$$

where D, C, and U denote down, constant and up segment type, respectively. K is a positive constant determining the duration of a segment relative to $1/T_s$, where typically K=1 is chosen. In the continuous-valued model described above, the model parameters are the functions $\mu(y, s)$, $\sigma(y, s)$.

The discrete-valued version of the DLR channel model applies an internal quantization procedure and assigns different discrete attenuation levels to the states of a Markov chain, see Fig. 2.

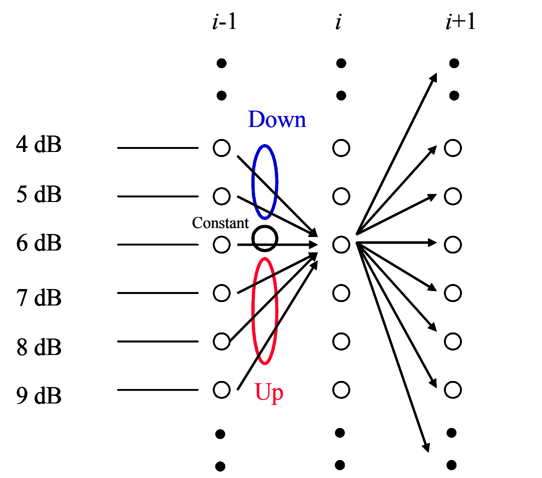

Fig. 2. DLR channel model as a discrete-valued 2nd order Markov chain. Grouping of transitions allows for a reduction of the number of transition probabilities.

A discrete-valued 2nd order Markov chain over M states is completely defined by its M^3 transition probabilities. With a quantization step size of 1 dB and M=40 a total of 64,000 transition probabilities has to be derived. This is very cumbersome to handle. However, grouping the 2nd order transitions into three groups reduces the number of transition probabilities to $3M^2$. Furthermore, all M transition probabilities emerging from a particular state can be very accurately described by a Gaussian distribution which results in only $3M$ distributions to describe the channel model, see Fig. 3. The use of Gaussian distributions was observed empirically to be valid for large datasets.

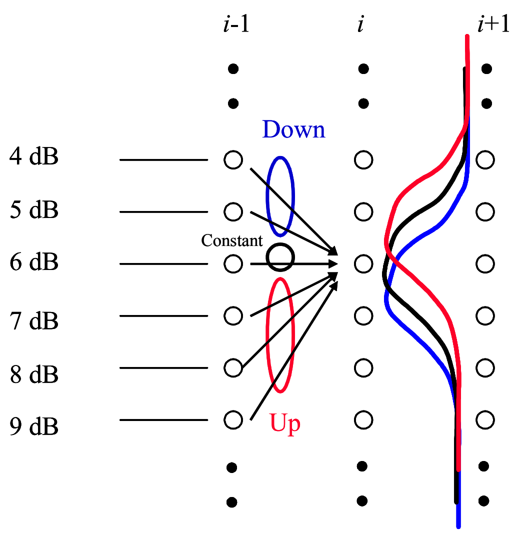

Fig. 3. DLR channel model: Description of the transition probabilities by Gaussian distributions.

A Gaussian distribution is fully described by its mean value and its standard deviation. Thus, to fully describe the DLR channel model, a total of $3M$ mean values and $3M$ standard deviations have to be determined.

The set of these $3M$ mean values and $3M$ standard deviations represents the specific channel model parameters (SCMPs) of the quantized version of the DLR channel model:

$$\mu_j^D, \sigma_j^D, \mu_j^C, \sigma_j^C, \mu_j^U, \sigma_j^U, \quad j = 1, \ldots M \,. \tag{2}$$

These parameters can be extracted from the measured time series of rain attenuation by means of a straightforward model parameter extraction process.

3. Model Parameter Extraction

This chapter describes the procedure of the DLR model parameters extraction.

3.1 Measured Time Series and Preprocessing

TESTCOM has been carried out long-term measurements of the received signal level on terrestrial microwave paths in several frequency bands. A model parameter extraction procedure was applied on measured data summarized in Tab. 1.

Path	Frequency (MHz)	Length (km)	Data amount (years)
TESCO – Chloumek	19 370.00	26.2	2
Strahov – TESTCOM	38 319.75	9.3	4
Úvaly – TESTCOM	38 491.25	15.2	3

Tab. 1. Overview of available measured time series of attenuation.

The sampling time of the measured data is 0.1 second. One-second block averaging is performed prior to parameter extraction in order to obtain a time series with a sampling time T_r = 1 s. A zero attenuation level is determined so that it corresponds to a monthly median value of the measured received signal level. Then, a moving averaging with a window size of 60 seconds is applied to remove fast fluctuations caused by a scintillation effect. The resulting sequence is denoted $x_n = x(nT_r)$, $n = 1,2,\ldots$ and has a sampling time of 1s. Filtering is employed, because the DLR model is intended to generate only slow variations of a signal caused by rain fading events.

3.2 Extraction Process

An extraction process is applied on the filtered time series $x_n = x(nT_r)$, $n = 1,2,\ldots$ in order to derive the SCMPs. Note that the measured time-series has a sampling rate 60 times larger than the sampling rate of the channel model. First, the time series x_n, $n = 1,2,\ldots$ is mapped onto a discrete-valued time-series d_n, where the elements of d_n can take on integers ranging from 1 to M representing attenuation levels.

Then, three matrices $\mathbf{H}^D$, $\mathbf{H}^C$ and $\mathbf{H}^U$ of size $M \times M$ assigned to the corresponding 3 types of segments are determined. An element h_{kl} of $\mathbf{H}^b$, $b \in \{D,C,U\}$ gives the number of transitions from attenuation level k to attenuation level l

between samples d_n and d_{n+K} for $K = 60$ and for all n; i.e. only samples separated by 60 seconds are considered; matrix $\mathbf{H}^b$ contains those transitions which are obtained for the case that $b = \Lambda(d_n - d_{n-K})$ with $K = 60$. A convenient determination of these matrices is to go sample-wise through the whole time series d_n and to increment the elements h_{kl} of $\mathbf{H}^b$ according to above rules.

The rows of matrices $\mathbf{H}^D$, $\mathbf{H}^C$, $\mathbf{H}^U$ provide distributions for every state. These distributions describe the probability of the transition from one state to another under the condition of the trend Λ which is either down, constant or up. Finally, the parameters described by eqn. (2) are extracted from the distributions.

The received signal fluctuates around the free space level which represents zero attenuation. That is why negative attenuation values may occur. In order to process these values properly, we considered in our investigation attenuation values ranging from -5 to +45 dB.

4. Results

This chapter presents the results of both the model parameter extraction and the simulation with the DLR channel model. The examples of extracted parameters and of generated time series of attenuation are shown. The first and the second order statistics of measured and simulated time series are compared.

4.1 Extracted Parameters

Fig. 4 shows the DLR model parameters extracted from the attenuation time series obtained on the path TESCO - Chloumek in 2003. Since the parameters describe transition probabilities, mean values are almost linearly dependent on an attenuation level. It means, the next attenuation level will have a similar value as the previous one for most of the time. However, significant relative differences are obvious between the curves for down, constant and up segments. Standard deviation slightly increases with an attenuation level and is minimal around the zero level (5 dB because of the shift reasoned in the last paragraph of the section 3.2).

Polynomial fitting of the model parameters from Fig. 4 was performed in order to provide one quantitative example of the continuous DLR channel model. The resulted polynomials are as follows:

$$\mu^D(y) = [-0.00399, 1.23473, -1.00784] \cdot \mathbf{y}_{(3)}$$

$$\mu^C(y) = [0.00046, 0.94223, 0.46872] \cdot \mathbf{y}_{(3)},$$

$$\mu^U(y) = [0.00410, 0.69399, 1.70162] \cdot \mathbf{y}_{(3)},$$

$$\sigma^D(y) = [0.00005, -0.00867, 0.32907, -0.00537] \cdot \mathbf{y}_{(4)},$$

$$\sigma^C(y) = [-0.00002, 0.00112, 0.03033, 0.51906] \cdot \mathbf{y}_{(4)},$$

$$\sigma^C(y) = [-0.00011, 0.00745, -0.06743, 1.32198] \cdot \mathbf{y}_{(4)},$$

$$\text{where: } \mathbf{y}_{(n)} = [y^{n-1}, y^{n-2}, \ldots, y, 1]^T. \quad (3)$$

Note that the discrete-valued model was actually used for calculations presented in the next sections.

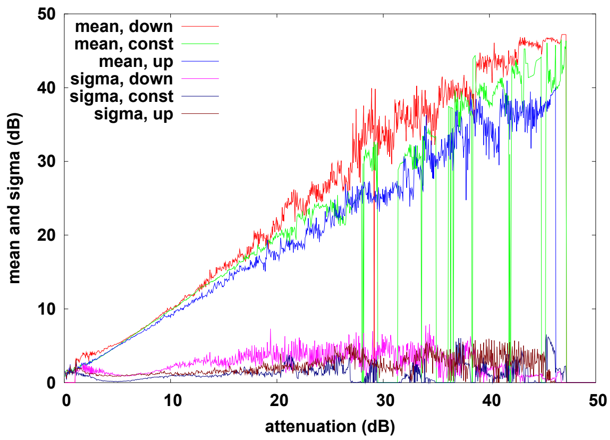

Fig. 4. Extracted parameters μ and σ as functions of the attenuation level and of segment type, path TESCO - Chloumek, year 2003.

4.2 Generated Time Series

The DLR channel model has been set up with above extracted parameters. It generates a time series with a sampling time of 1 minute. The generation followed eqn. (1) with parameters $T_s = 60$ s and $K = 1$. The duration of all generated time series of attenuation has been 1000 days.

Fig. 5 shows an example of an artificial time series of attenuation generated by the DLR channel model with a parameter set extracted from the TESCO - Chloumek measured data. The received signal level relative to the free space level is depicted. The simulated time-series looks very similar to those which have been measured.

4.3 Statistics

Comparisons of statistics are presented in this section. First order statistics are represented by cumulative distributions of attenuation (CDA). The second order statistics are represented by fade duration distributions.

4.3.1 Cumulative Distributions

Figs. 6 through 8 show the comparison of the cumulative distributions of attenuation (CDA) calculated from measured time series (“*meas*”) and from generated ones (“*simul*”). Note that model parameters were always extracted from the same measured data that was used for comparison.

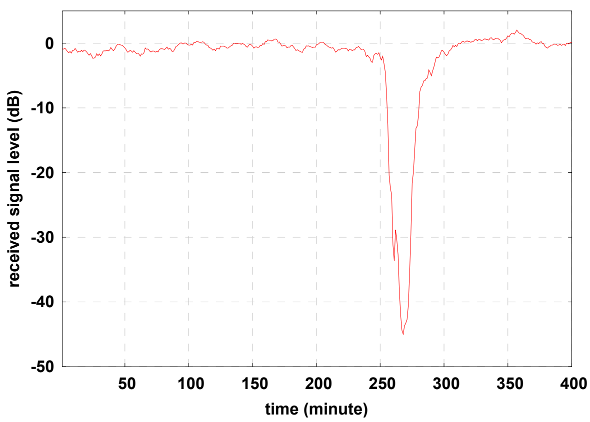

Fig. 5. Artificial time series of received signal level generated by DLR model with parameter set extracted from path TESCO - Chloumek, year 2003.

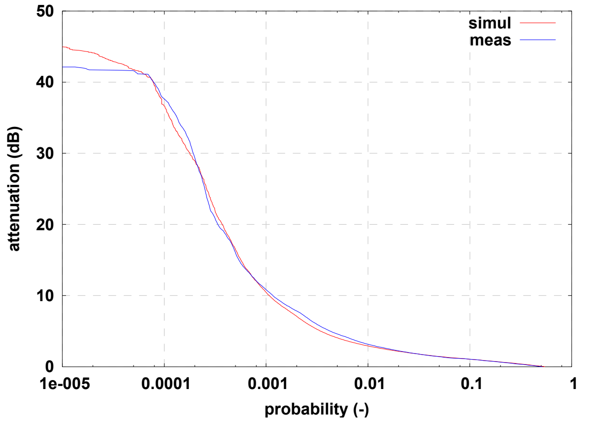

Fig. 6. CDA for path TESCO - Chloumek, year 2003.

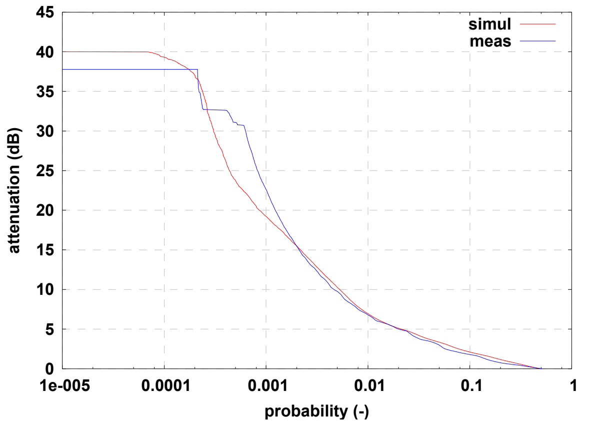

Fig. 7. CDA for path Strahov - TESTCOM, year 2002.

4.3.2 Fade Duration Statistics

Figs. 9 through 11 show the fade duration statistics of measured and generated time series. These statistics represent the probability that an attenuation sample at an arbitrary time instant is part of a fade which exceeds a given attenuation level for a time duration which is longer than the value on the abscissa.

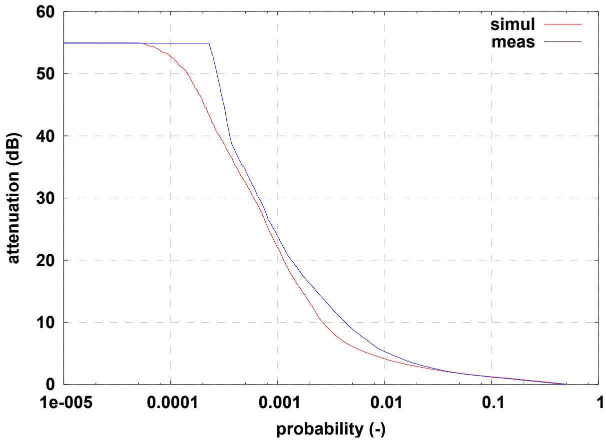

Fig. 8. CDA for path Úvaly - TESTCOM, year 2003.

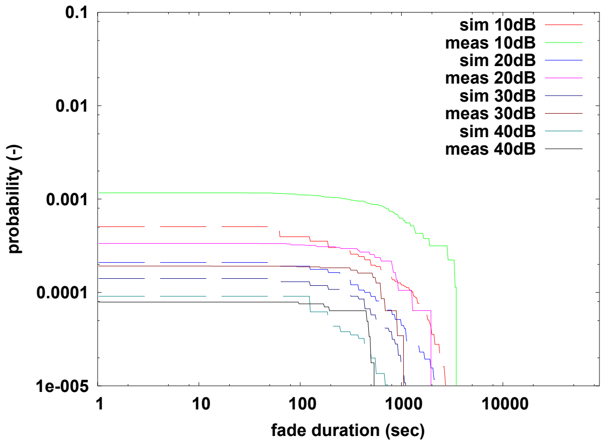

Fig. 9. Fade duration statistics obtained from measured and simulated time series for path TESCO - Chloumek, year 2003.

4.4 Discussion on the Results

The figures reveal a very good fit of measured and simulated time-series in terms of the first order statistics (cumulative distributions of attenuation). The best fit was obtained for data from the TESCO - Chloumek path, see Fig. 6. Differences at higher attenuation values are generally larger than at lower attenuation values.

The fit of the second order statistic is not as good as of the first order statistics. Figs. 9 through 11 indicate that the generated fade events can be shorter than the measured ones. These differences are smallest for the Strahov – TESTCOM path. These differences are generally not so large when the DLR channel model is applied to a satellite link. One of the reasons for these differences might be that spurious multipath fading which often occurs burst-like (many short and deep fades within a short amount of time) influence the SCMPs such that long fades are less likely to occur. These effects cannot be simulated by the DLR channel model, since it does not follow fast fluctuations.

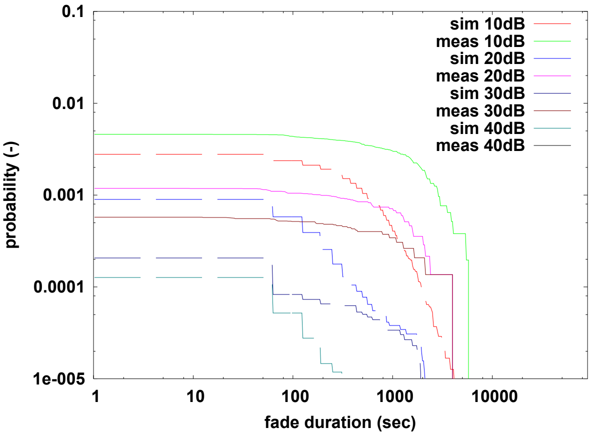

Fig. 10. Fade duration statistics obtained from measured and simulated time series for path Strahov - TESTCOM, year 2002.

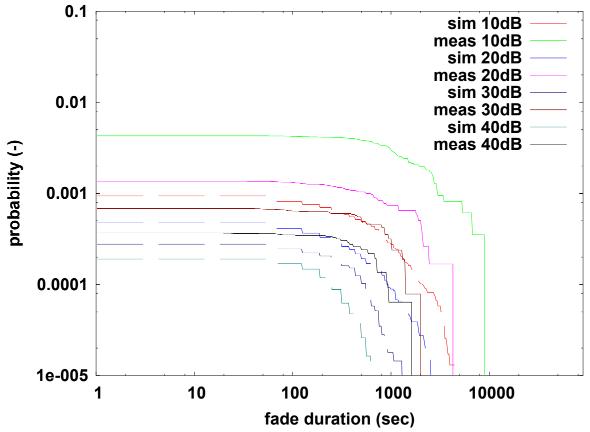

Fig. 11. Fade duration statistics obtained from measured and simulated time series for path Strahov - TESTCOM, year 2003.

5. Conclusions

Rain fading generators are intended to support the simulation of microwave or millimeter wave radio systems that are impaired by the rain attenuation. The results of the DLR channel model parameter extraction were presented in this paper. Time series of received signal level measured on the three terrestrial microwave paths were processed to obtain the parameters for the model. In contrast to satellite paths, at which the DLR model has proven excellent performance, terrestrial paths are more likely to be subject to multipath propagation. It seems that this effect may influence the extraction process and cause poorer results with respect to fade duration statistics.

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References

[1] FIEBIG, U.-C., CASTANET, L., LEMORTON, J., MATRICCIANI, E., PÉREZ-FONTÁN, F., RIVA, C., WATSON, R. Review of propagation channel modelling. In *Proceedings of 2nd International workshop of COST280 Action.* May 2003, p. 153 – 164.

[2] CASTANET, L., LEMORTON, J., LACOSTE, F., RIVA, C., MATRICCIANI, E., FIEBIG, U.-C., VAN DE KAMP, M., MARTELLUCCI, A. Development and validation of time series synthesizers for Ka-band satellite communication systems. In *Proceedings of 10th Ka-Band Utilization Conference.* Vicenza (Italy), October 2004.

[3] FIEBIG, U.-C. Modelling rain fading with a time-series generator considering seasonal and diurnal variations. In *Proceedings of the 8th Ka-Band Utilization Conference.* Baveno/Strese (Italy), 2002.

[4] FIEBIG, U.-C. Satellite channel modelling for rain fading. In *Proceedings of AAIA International Communications Satellite System Conference.* Yokohama (Japan), 2003.

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