Multipath propagation fade duration modeling of Land Mobile Satellite radio channel

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This contribution presents a modeling method of the fade duration caused by multipath propagation on a land mobile satellite channel. The model is based on the measurement of a satellite channel and applied to calculate the model parameters. The proposed model is based on a partitioned Fritchman's Markov chain which is applicable to calculate the complementary cumulative distribution function of the fade duration process. The dependency of the model parameters on the attenuation threshold will be also shown. Therefore the model will be available to calculate the fade duration distribution for any threshold what can be applied later in attenuation time series synthesis.

1. Introduction

The propagation on a Land Mobile Satellite (LMS) radio link is highly influenced by the shadowing effects of buildings and vegetation, or by the multipath propagation. This kind of fading arises due the multiple reflexions of the radio waves on the surrounding objects; therefore not only the direct signal is received. The characteristics of fading highly depend on the surroundings. During the design of LMS radio links one can apply the distribution function of the attenuation or the fade duration statistics to determine the fluctuation of the received signal. The fade duration is an important dynamic parameter of the path attenuation which gives the duration of fading higher than a given attenuation threshold. Therefore the fade duration is always calculated for multiple threshold levels.

In our contribution a digital model with Markov chain will be introduced, which is also applicable to determine the statistical parameters of the fade duration. The model is based on the measurement data of a real LMS channel what has been used to calculate the model parameters.

The proposed model is a partitioned Fritchman's Markov chain which is applicable to describe the stochastic fade duration process and also to calculate the Complementary Cumulative Distribution Function (CCDF) of the fade duration. The expressions to calculate the model parameter dependency on the threshold level will be also introduced. Therefore the model will be applicable to calculate the CCDF of fade duration for any desired threshold level which may lead us to the synthesis of attenuation time series in the future.

Table 1. Parameters of the measured LMS channel

Satellite	MARECS (d=39150 km)
Elevation	24°
Frequency	1.54 GHz
Sampling rate	300.5 Hz
Channel ID	14
Environment	Highway
Duration	81.2 min
Vehicle speed	60 km/h

2. Description of the measured LMS channel

To investigate and model the LMS radio channel we applied real measurement data as a starting point. The measurements have been performed by the DLR (Deutsches Zentrum für Luft- und Raumfahrt) between 1984 and 1987 [1], the parameters are detailed in *Table 1*.

The connection is the radio channel of the geostationary satellite Marecs operating at 1.54 GHz in the L-band. The measurement has been performed on highway on the board of a vehicle moving with 60 km/h speed, the measurement duration was 81.2 minutes. During the measurement the received power has been sampled with 300.5 Hz frequency and the data were recorded after normalization. The normalization was so performed that the average received power of 0 dBm represents the level of the fading-free signal.

During the measurement described above, due the movement of the receiver the receiving path has been crossed with different objects and as a result of the changing in the reflexion environment the signal arrived to the receiver on multiple paths. The above effects result in multipath fading which can be stochastically modeled as it will be described in the next sections.

3. Fade duration on the radio channel

The fade duration is one of the most important dynamic parameter of the attenuation on radio connections; it gives the time length when the attenuation is higher than the given threshold. The precise estimation of fade duration is essential when designing wireless communication systems like BFWA, B3G, 4G mobile systems or LMS channels. In calculations of the system outage or availability time or when sharing the resources or selecting different coding methods, the measured or modeled fade duration statistics plays an important role. The interfade duration is of similar importance, which is the duration between two consecutive fadings and its calculation and modeling is very similar to the method what we apply in the case of fade duration.

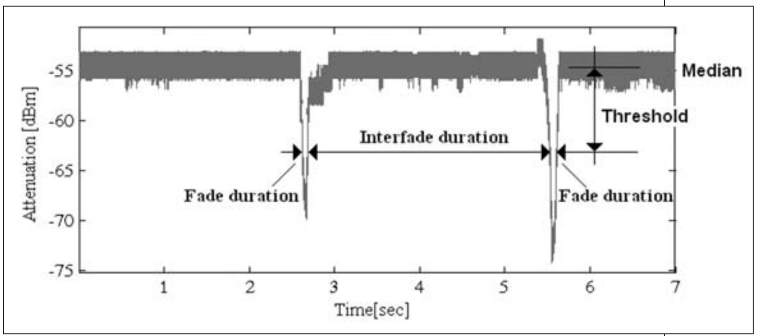


Figure 1.
Measured attenuation time series with fading and inter-fading

Figure 1 shows a typical attenuation time series with multiple fade events indicating the fade and interfade durations, respectively.

The Complement Cumulative Distribution Function (CCDF) of the received power on a radio channel is a first order statistics what is often depicted to qualify the channel or rather the radio connection. The fade duration is determined usually relatively to the median level of the received power for different thresholds, then the complementary distribution of the number of fade events are depicted as the function of fade duration.

4. Modeling with partitioned Markov chain

The ITU-R (International Telecommunication Union, Radio communication Sector) proposes a two-component model for fade duration [2], which models the fast fading with log-normal distribution and the slow fading with power-law one, ensuring the smooth transition between the two stages.

To model the fading process caused by the multipath propagation we propose a Markov model, which can be applied not only to the stochastic modeling of the fading process but it allows the exact calculation of the fade duration distribution for different thresholds. Comparing with the ITU-R model, this digital model handles uniformly the short and long fading, respectively. In the model we apply an N=5 state partitioned Fritchman's Markov chain [3], where 4 states are representing the fading and one state the inter-fading events *(Figure 2)*.

The transition probabilities p_{ij} of the Markov chain are depicted in *Figure 2* and its feature is that there are no transitions between the states in the same partition. This is the simplification in the Fritchman's model and it can be applied because the states in a partition are representing same type but different length of events – in our case fade and interfade events – therefore it can be supposed that there are no transitions between them.

The transition matrix of the model can be written according to the Equation (1), where we can observe the absence of transitions at the specific places.

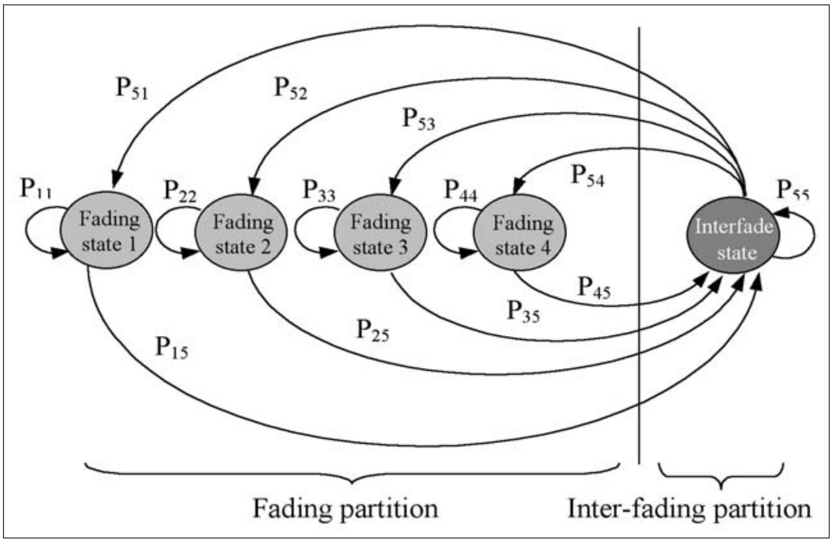
$$\overline{P} = \begin{pmatrix} p_{11} & 0 & 0 & 0 & 1-p_{11} \\ 0 & p_{22} & 0 & 0 & 1-p_{22} \\ 0 & 0 & p_{33} & 0 & 1-p_{33} \\ 0 & 0 & 0 & p_{44} & 1-p_{44} \\ p_{51} & p_{52} & p_{53} & p_{54} & 1-\sum_{i=1}^{4} p_{5i} \end{pmatrix} \quad (1)$$

This model – unlike to the multiple-state models, where every attenuation level corresponds to a state in the Markov model – can describe the stochastic behavior of the fading process with the distribution functions of the partitions. This model has been developed by Fritchman to characterize burst errors on binary communication channels, what we have been adapted to the fading process.

The Fritchman's model can be applied to calculate the complementary cumulative distribution function of the fade and interfade duration [3] according to the Equations (2) and (3):

$$F_F^C(n) = \sum_{i=1}^{N-1} \frac{p_{Ni}}{p_{ii}} p_{ii}^n \quad (2)$$

Figure 2.
5 state partitioned Fritchman's Markov model



$$F_I^C(n) = (\sum_{j=1}^{k} \frac{Z_j p_{jN}}{Z_F p_{NN}}) p_{NN}^n \quad (3)$$

where N=5 is the number of states and p_{ij} is the probability of state transitions.

In Equation (3), Z_i denotes the steady state probabilities, and Z_F is the fading partition probability. They can be calculated using Equations (4) and (5):

$$Z_N = \frac{1}{1 + \sum_{i=1}^{k} \frac{p_{Ni}}{p_{iN}}} \quad (4)$$

$$Z_i = \frac{p_{Ni}}{p_{iN}} Z_N \quad (5)$$

Expression (2) gives the probability of a fade event being longer than the given duration. Earlier investigations, described in [5], showed that the modeling of the inter-fade duration and calculating its complementary distribution with the Equation (3) can not be applied with proper accuracy because there is only one state representing it in the Markov chain. Therefore, to model the interfade duration with appropriate precision, a different Fritchman's model must be applied, a similar one as the one depicted on *Figure 2*, where multiple states are assigned to the interfade duration and one state to the fade duration.

5. Model parameterization

In case of Markov models the parameterization is usually the process of determination of the transition matrix elements. The Fritchman's model is widely used due its relatively simple parameterization and the correct representation of the modeled process. We should also take into account that the Fritchman's model with a single error state can be applied only to model communication channels with renewing feature [6].

To determine the parameters of the Markov chain (see Figure 2) we apply the gradient method as described in [4]. The point of the method is that the logarithmical CCDF of the measured fade duration can be approximated with linear according to the equation (6), afterwards the transition probabilities of the Markov chain can be determined from the line parameters.

$$\log(F_F^C(n)) = \log(\sum_{i=1}^{N-1} \frac{p_{Ni}}{p_{ii}} p_{ii}^n) \approx \begin{cases} \text{for small n:} \\ n\log(p_{N-1N-1}) + \log(\frac{p_{NN-1}}{p_{N-1N-1}}) \\ \text{for large n:} \\ n\log(p_{11}) + \log(\frac{p_{N1}}{p_{11}}) \end{cases} \quad (6)$$

One can see that the expressions on the right side of the equation correspond to the equation of lines; the gradient and crossing with the abscissa give the transition matrix elements.

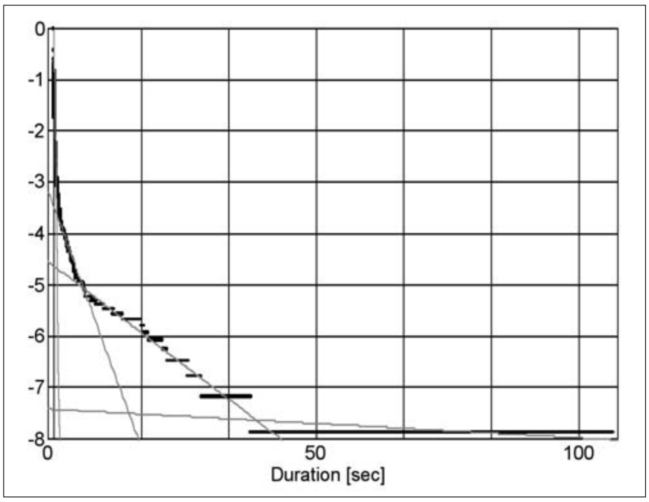


Figure 3.
Linear regression of the logarithmic complementary fade duration distribution at 5 dB

The parameterization process is depicted on the *Figure 3* in case of 5 dB threshold level.

The number of regression lines determines the state numbers in the Markov chain and their number is depending on the required lines to properly approximate the original logarithmical CCDF. In our case four numbers of lines are sufficient, which results in four fading states in the Markov chain.

Figure 4.
Measured and modeled fade duration distribution at 5 dB

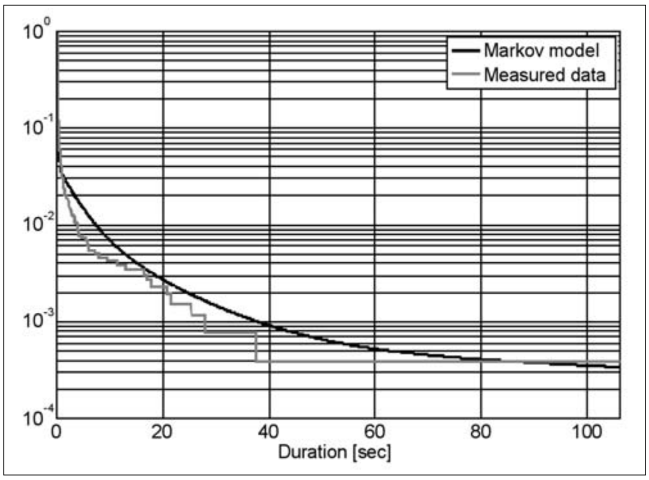


Table 2.
Parameters for Equations (7 and 8)

Transition probability	a_{ii}	b_{ii}
p_{11}	-1.849e-007	1.0000000
P_{22}	-8.646e-007	0.9995000
P_{33}	-2.949e-006	0.9990000
p_{44}	-8.963e-006	0.9795000
	a_{Ni}	b_{Ni}
p_{51}	1.037e-007	0.0003791
p_{52}	3.340e-007	0.0044070
p_{53}	3.652e-006	0.0317600
p_{54}	1.093e-005	0.5377000

After the determination of the transition matrix elements using Equation (2), the complementary distribution function of fade duration can be calculated and by depicting it together with the original measurement one can see the proper approximation (see *Figure 4*).

The method described above can be also applied to model the fade duration for different threshold levels, usually in the range of 1-30 dB.

6. The threshold dependency of the model

If we perform the modeling process for other different thresholds and depict the transition matrix elements of p_{ii} and p_{5i}, one can see that with the cubic equations given in (7 and 8) the threshold A dependency of the matrix can be well approximated:

$$p_{ii}(A) = a_{ii} * A^3 + b_{ii} \quad (7)$$

$$p_{Ni}(A) = a_{Ni} * A^3 + b_{Ni} \quad (8)$$

In *Table 2* we can see the parameters necessary to calculate the transition matrix threshold dependency.

With applying the above constants it is possible to calculate the elements of the transition matrix for any desired threshold level and the CCDF of the fade duration can be also computed.

In *Figures 5 and 6* one can see the threshold dependency of the model parameters and the approximations applying the Equations (7 and 8).

By this method we can calculate the transition probabilities for the 5 state Fritchman's Markov chain of the fade duration at different threshold levels. It allows computing the CCDF of fade duration which is depicted in *Figure 7* for 2-10 dB thresholds.

The cumulative complementary fade duration distribution functions can be also applied to calculate the statistics of a radio channel for a desired time period. Depicting of the total number of fade events longer than a given duration is also a common graphic method. To

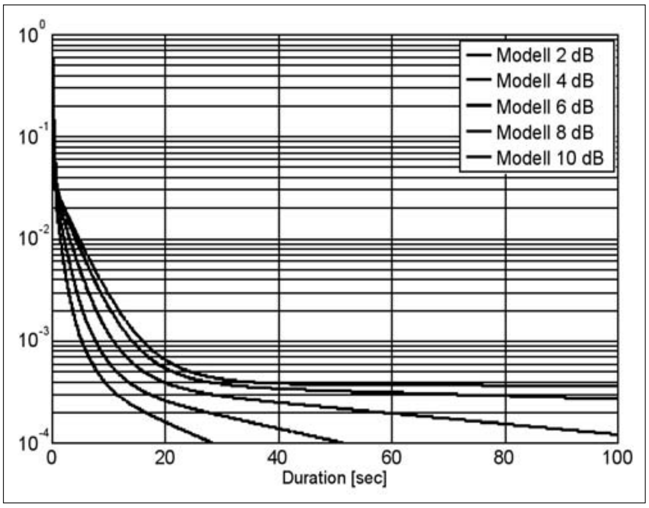


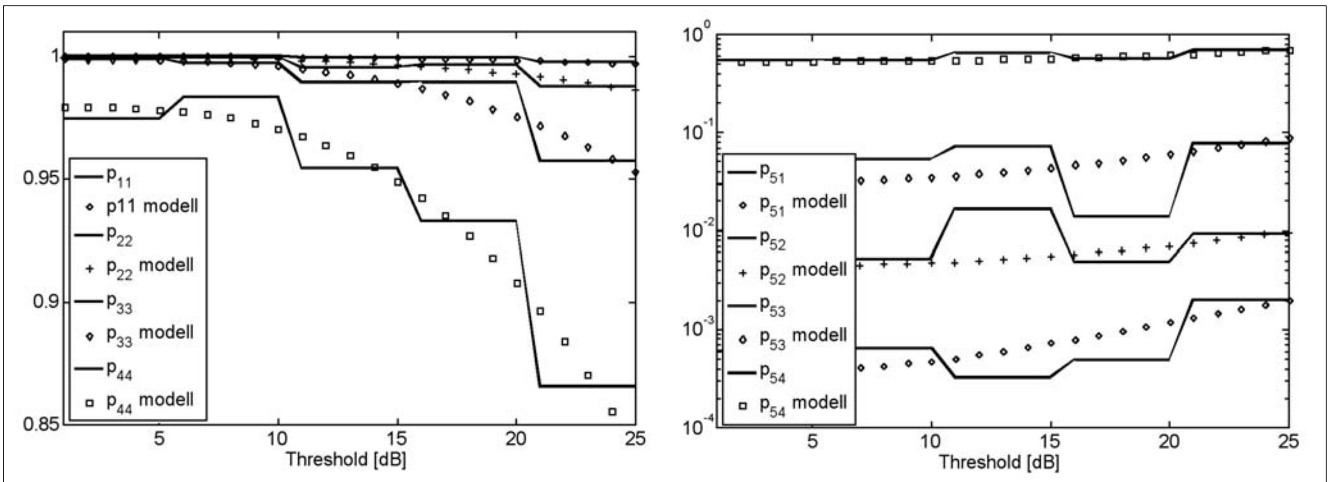
Figure 7.
Modeled fade duration complementary distributions for 2-10 dB thresholds

create this kind of statistics the modeled fade duration CCDF functions must be multiplied with the total number of fade events on the actual channel. This parameter is available from measurements and statistics and it is also applied by the earlier mentioned ITU-R model [2].

7. Summary

In our contribution we proposed a partitioned Fritchman's Markov chain to model the fade duration process caused by the multipath propagation on a Land Mobile Satellite radio channel. The parameterization of the model is the determination of the transition matrix elements of the Markov chain what can be performed from the original measurement data of the channel. This kind of Markov model is applicable to calculate the CCDF of fade duration which is an important statistical data for the radio channel designers.

Figure 5-6. Threshold dependency of pii and p5i transition probabilities



The threshold dependency of the Markov model parameters are also shown, which results that the complementary distribution functions can be calculated for any desired thresholds. This may lead us to develop attenuation time series generators and synthesize measurement data for any required duration.

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