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| Fascicle |
| Guidelines for parameter extraction and testing of land mobile satellite narrowband channel models |

Scope

This fascicle provides step-by-step methods to extract channel model parameters from experimental data that are consistent with the statistical model for mixed propagation conditions using a two-state semi-Markov chain approach for the land mobile-satellite service (LMSS) channel models in Section 6 of Recommendation [ITU-R P.681](http://www.itu.int/rec/R-REC-P.681/en)-10.

# 1 LOS calibration

The first step consists in calibrating the line-of-sight (LOS) level. The link budget is defined as follows:

  (dB)

where Pt,r, Gt,r, and Lt,r  are respectively the transmitted and received power, the transmitter and receiver antenna Gain, the feeder loss. Finally, *L*p corresponds to the path loss.

The time series calibration is obtained while performing the following corrections:

– Compensation for the Tx-Rx distance variations during the experiment.

– Compensation for the Transmitted power variation (in case the transmitted power is recorded).

– Compensating for the Tx and Rx antenna gain (in case the relative directions of the Tx and Rx are known as well as their antenna pattern).

**–** Compensation for time varying instrumental biases.

# 2 Shadowing and multipath envelope extraction

This step will deal with the calculation, from the time-series files, *R*(*x*), of the two parameters of the Rice distribution, the direct signal level (or shadowing), *A*(*x*), and the Rice K-factor (direct signal to multipath ratio), *K*(*x*).

The Rice distribution is given by the equation

 

where a is the direct signal's amplitude and describes the amount of diffuse multipath. The convention has been taken where the LOS level is equivalent to a normalized value *a*LOS=1 (0 dB).

The two parameters in the above equation are given in dB as follows:

  and .

And, of course, *R*=20log(*r*). One further parameter provided is the average multipath power, MP (dB/LOS), given by:

 .

*A* and *K* parameters extraction will be performed using the so called Method of Moments [Greenstein et al., 1999] applied on a sliding window representing a so-called small area **(10 to 30 wavelengths)** where stationarity is assumed. See the example on Figure 1.

Figure 1

Time series measured and shadowing



# 3 States identification

The next step is identifying the sections of data corresponding to the GOOD and BAD states. The classification is performed using the fuzzy logic classification algorithm "fuzzy c-means", as available in MATLAB (function fcm) [Bezdec, 1981]. The principle is the same as for the K-means algorithm, except that the fuzzy c-means does not make a ‘hard’ decision, but each data sample is given a degree of belonging to clusters. Thus, the MATLAB function fcm provides a parameter, the so-called "membership" parameter in the [0, 1] interval, indicating the degree to which one element in the population to be classified belongs to each possible cluster.

The classification may be done on the values of *A*, or on the values of A and K. Here, there is no absolute criterion to make this choice. Empirically, it is just observed that use of the A value provides a better classification for lower band (1 – 5 GHz), and that use of the A and K values is better for the upper band.

Two possible clusters are asked from fcm. Using a 0.99 membership threshold for lower band (1‑5 GHz) or 0.9 membership threshold for higher band (10-20 GHz) for each state, an intermediate state in between the GOOD and BAD is generated in the intermediate region.

A second pass through the GOOD-indefinite-BAD state series allowed classifying the "indefinite" events as either GOOD or BAD depending on the surrounding events. If an "indefinite" sample is surrounded by both a GOOD and a BAD sample, it is marked as GOOD during this second pass. This prevented small peaks or troughs in the middle of long states to produce a transition to a very short event, thus acting as some sort of hysteresis process.

Figure 2 illustrates how the membership parameter varies for the values of *A*. The obtained state time-series is illustrated in Figure 3.

Figure 2

Membership parameter resulting from the classification of the A values,
and membership thresholds used



Figure 3

Resulting GOOD and BAD events out of the classification processing



***Note 1:*** *The number of states increases with the threshold values*

***Note 2:*** *classification over AK provide more states than AA.*

***Note 3:*** *the fuzzy logic includes random stages that can lead to different results on the same dataset. However, trends remain the same and in practice only very minor differences are observed*

# 4 1st order parameters of the Loo distribution

The next step is modelling the variations of *A* and *MP* in each state occurrence. This is because the model assumes different Loo parameters with each state outcome. To perform this particular study, only sufficiently long events (longer than the 15th percentile for each state) are used in order to be able to compute standard deviations of *A* with each particular event.

For lower frequency, the distribution of the state direct signal means, *<A>*, follows a Normal distribution. An example of experimental CDF of *<A>* can be seen in Figure 4 together with fitted Normal distributions.

Figure 4

CDFs for <A> parameter (GOOD state and BAD state with respective Gaussian fitted distributions and overall series with respective weighted mixed distribution). Example for low frequency (here S band)



However, this is not true anymore for higher frequency as can be seen in the Figure 5 then the fit will be done directly on the A samples. For the GOOD state, a normal fit will be used. For the BAD state, it is recommended to use a truncated normal definition. Here, (thanks to 2 parameters A\_mean\_min and A\_mean\_max) the range values is defined where the fit should be done in order to reject noise receiver saturation. These values will depend of the measurement set up. In this example (sub urban Ku) a 25 dB dynamic range is observed. A\_mean\_min = -20 dB, and A\_mean\_max = ‑3 dB are used. Figure 6 is an example for high frequency. Please note that a relation can be found between “A\_mean\_min” / “A\_mean\_max” and the probability range in the equations 18a and 18b of Recommendation ITU‑R P.681.

Figure 5

CDFs for <A> parameter (GOOD state and BAD state with respective Gaussian fitted distributions and overall series with respective weighted mixed distribution). Example for high frequency (here 11 GHz)



Figure 6

CDFs for A parameter (GOOD state and BAD state with respective Gaussian fitted distributions and overall series with respective weighted mixed distribution). Example for high frequency (here 11 GHz)



Empirical relationships are then worked out to link *<A>* to the other two variables: *std(A)* and *<MP>*, the standard deviation of <*A>* in a given state event and the average value of *MP* in the event. An example of relation between *<A>* and *std(A)* obtained for both states is shown in Figure 7 (for lower band) and Figure 8 (for higher band). It can be observed in the figures that the outliers, the too short events, are not been taken into consideration in the extraction of a regression fit.

Figure 7

Relation between <A> and std(A) for both states (S band)



Figure 8

Relation between <A> and std(A) for both states (Ku band)



Finally, the relationship between *<A>* and *<MP>* is worked out. It is preferred to use the parameter *K=A−MP*, as this parameter provides a much clearer view of the existing trend, i.e., a more marked slope. An example of fitted relationship is illustrated in Figure 9 and Figure 10. For these parameters, a unique relationship whatever the state (i.e., either GOOD or BAD) might be preferred.

Figure 9

Relationship between <A> and <K> for GOOD, BAD and both states (S band example)



Figure 10

Relationship between <A> and <K> for GOOD, BAD and both states (Ku band example)



***Note 1:*** *A\_mean\_min and A\_mean\_max will influence the value of* *, as it define the value to take into account in the reference time series*

***Note 2:*** *will influence the value of* 

# 5 Transition slopes between states

The slopes in-between states have also to be characterized. **For this purpose, two alternatives can be envisioned.** For the first one [Fontan, 2011] reference is made to Figure 11 where the average slope between two events is defined base on the first and last inflection points. The second alternative [Montenegro-Villacieros, 2011] consists in defining a transition based on the first and last points respectively above and below the mean values of surrounding states.

A linear relation between the transition slope and the step in shadowing between 2 states is then looked for. An example of regression is shown in Figure 12.

The identified transition zones are then discarded from the following parameters extraction processes.

The outputs of this step are the 2 parameters denote f1 and f2 in the length transition model of Recommendation ITU-R P.681, Section 6.

Figure 11

Definition of average transition slope



Figure 12

Relation between transition slopes and ΔA



# 6 Markov and semi-Markov chain parameters

After performing the above classification, it is possible to extract the log-normal distribution parameters for the semi-Markov model. An example of fitted log-normal distributions respectively for the GOOD and BAD states is illustrated in Figure 13 and Figure 14.

Figure 13

Semi-Markov model. Measured and fitted log-normal distributions
for the GOOD and BAD state durations (S band example)



Figure 14

Semi-Markov model. Measured and fitted log-normal distributions for the GOOD
and BAD state durations (Ku band example)



# 7 Shadowing correlation length

The shadowing component is usually modelled as a Gauss Markov process with correlation *Lcorr*, and then the theoretical cross-correlation function of the process is given by:

 

Let's consider the MoM at Step 2 is applied on a sliding window with fixed duration *N.Ds* where *N* is the number of samples of the window and *Ds* is the sampling distance. The effect of the MoM on the Shadowing distance series is the same as that of a simple flat sliding window filter and the impact on the cross-correlation function can be closed-form quantified as follows:

 

Where: 

From the above expression, it can be deduced that the filtering step widens the cross-correlation function of the shadowing process.

When processing experimental data in order to parameterize a state oriented channel model, it is also desirable to process separately data corresponding to the different states. As a consequence, the datasets consist of disjoints blocs of continuous data which do not enable to compute easily an average cross correlation function (it is at least not possible to compute it from fft). It is then proposed to use another second order moment *K2* on the whole datasets as follows:

 

The *K2* moment is asymptotically related to the cross correlation *R* function as follows:

 

Hence, using either the cross-correlation function or the *K2* moment should not make any difference from the parameter estimation point of view. However, based on Monte-Carlo numerical simulations, it has been observed that the convergence rate of the *K2* moment is faster than that of the cross correlation function (i.e.: less data are required in order to get a good estimation of the *K2* moment). It has also been observed that, using the *K2* moment, the continuous blocs of data should last about 50 times longer than the estimated correlation length in order to get an unbiased estimation of the correlation length. For shorter data blocs, the correlation length will systematically be underestimated.

Finally, the following method is proposed in order to estimate the shadowing correlation length: first the second order moment is computed on continuous blocs of data as long as possible and averaged over all the considered blocs of data. Then, knowing the sliding window length used to extract to shadowing distance series the *K2* curves are fitted in a RMS sense in order to estimate the correlation length.

# 8 Summary of the SISO model input parameters

Table I

2-state semi-Markov SISO model input parameters

|  |  |
| --- | --- |
| Parameter | Description |
| (µ,σ)G,B | Mean and standard deviation of the log-normal law assumed for events duration(meters), § 6 in this document, example of fit Figure 13 and Figure 14 |
| durmin,G,B | Minimum state event duration (meters) |
| (G,B,G,B) | Parameters of the MA G,B distribution, (MA being the average value of the direct path amplitude A over one event (dB). § 4 in this document, examples of fit Figure 4 and Figure 6 |
|  g1G,BMA+g2G,B | Standard deviation of A, ΣA, G, B,(one 1st order polynomial for each state). § 4 in this document, examples of fit Figure 7 and Figure 8 |
| h1G,BMA+h2G,B | Multipath power, MPG,B,  (one 1st order polynomial for each state), (dB).§ 4 in this document, examples of fit Figure 9 and Figure 10 |
| LcorrG,B\* | Direct path amplitude correlation distance (meters). § 7 in this document |
| f1ΔMA+f2 \* | Transition length, Ltrans ,(one single 1st order polynomial), (meters). § 5 in this document, main principle Figure 11 and fit example Figure 12) |
| [pB,min, pBmax] | Probability range to consider for the MAG distribution. § 4 in this document, related to A\_mean\_min and A\_mean\_max with the equations 18a and 18b of Recommendation ITU‑R P.681.  |

# 9 MIMO correlation matrix

The following procedure is proposed to extract a shadowing SIMO, MISO or MIMO correlation matrix from an experimental dataset that is compatible with state oriented channel models. It is especially suited to the single satellite dual polarized MIMO channels; with additional adaptations, this procedure should also be used for spatial MIMO channels.

Based on [Carrie, 2011], a MIMO correlation matrix compatible with state oriented channel models has to be estimated from a normalized distance series. This procedure is therefore necessarily applied after the above steps 1 to 6. Then, for each state episode *k*, the shadowing *Ak* is normalised into  as:

 

where  and  are estimated at step 6.

Finally, the coefficient of line *i* and column *j* of the MIMO correlation matrix, corresponding to the correlation coefficient between the channels *i* and *j*, is computed as:

 

# 10 Parameters to tune in order to optimise the parameters inversion

There are 4 parameters which should be adjusted:

• C\_fl is the membership threshold used in the fuzzy logic. The ranges are usually between 0.9 and 0.99. It can be interesting to test if the fuzzy logic may be applied in A values, or A/K values. Some guidelines are given in § ‎3).

• A\_mean\_min and A\_mean\_max will mostly influence the CDF fit and thus, the  value

• dminB, the minimum state event duration

# 11 Variables used for the testing of LMSS narrowband channel model

a) Fade margin and K-factor CDF

The root mean square of absolute differences testing method is proposed to calculate the errors:

Considering fading margins and Rice factors cumulative distribution function at fixed probability levels, e.g. 0.5%, 1%, 5%, 10%, 30%, 50% and 90% of the time. It is possible also to derive the probability levels at constant sample fixed values of the CDF (e.g. 0:30 dBs for fading margin and 10:20 for the Rice factor).

Calculate the root mean square of the absolute difference of fading margin / Rice factor as:

 Error\_Abs = xexperimental – xmodel;

 Error\_Abs\_RMS = norm(Error\_Abs(~isnan(Error\_Abs)));

b) Average fade duration

The same method applied for fading margin and K-factor may be applied for average fade duration where percentage of time is replaced by fade duration.

Considering fading levels at fixed average fade duration values. Calculate the root mean square of the absolute difference of fading levels as:

 Error\_Abs = xexperimental – xmodel;

 Error\_Abs\_RMS = norm(Error\_Abs(~isnan(Error\_Abs)));

# 12 Guidelines for acceptance of new input parameters

The first acceptance criteria must be the fit of the CDF as can be seen in Figure 4 and Figure 6.

The second acceptance criteria are the RMS of absolute difference of fading margin (Err\_FM), Average fade duration (Err\_AFD), and Rice factor (Err\_K), the input parameters are accepted if the following three criteria are all fulfilled:

1 Err\_FM ≤ 2dB

2 Err\_AFD ≤ 1 m

3 Err\_K ≤ resolution\_K (Synthetic Rice factor series computed applying the Method of Moments on the fading synthetic series)

The resolution K is calculated as the RMS difference between the CDFs of the synthetic time series Rice factor and the synthetic time series of the Rice factor after applying the Method of Moments.

# 13 Error on current parameters

The next tables give the fit performances in Recommendation ITU-R P.681-10. All the proposed performance criteria were respected, except for the “residential” environment with a 45° elevation (highlight in red).

Please note the fit have been proceed with data presented in [5] [6] for S and C band, and [7] for Ku‑band.

Testing results for f = 2.2 GHz

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Elevation (°)Environment | 20 | 30 | 45 | 60 | 70 |
| Wooded | OK | OK | OK | OK | OK |
| Suburban | OK | OK | OK | OK | OK |
| Urban | OK | OK | OK | OK | OK |
| Village | OK | OK | OK | OK | OK |
| Residential | OK | OK | NOK | OK | OK |

 Err\_fm

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Elevation (°)Environment | 20 | 30 | 45 | 60 | 70 |
| Wooded | 1.0 | 0.6 | 0.9 | 0.9 | 0.2 |
| Suburban | 0.7 | 0.5 | 0.8 | 0.4 | 0.5 |
| Urban | 2.1 | 1.2 | 1.0 | 0.7 | 0.4 |
| Village | 1.1 | 1.1 | 0.9 | 0.4 | 0.3 |
| Residential | 0.7 | 0.2 | 2.2 | 1.0 | 0.1 |

Err\_afd

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Elevation (°)**Environment** | **20** | **30** | **45** | **60** | **70** |
| Wooded | 0.23 | 0.12 | 0.09 | 0.06 | 0.07 |
| Suburban | 0.28 | 0.17 | 0.12 | 0.13 | 0.17 |
| Urban | 0.58 | 0.33 | 0.34 | 0.23 | 0.18 |
| Village | 0.21 | 0.22 | 0.12 | 0.07 | 0.08 |
| Residential | 0.15 | 0.12 | 0.11 | 0.18 | 0.06 |

F=2.2 Err\_K

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Elevation (°)Environment | 20 | 30 | 45 | 60 | 70 |
| Wooded | 3.7 | 3.1 | 2.8 | 2.9 | 2.6 |
| Suburban | 1.9 | 1.6 | 1.4 | 1.8 | 3.0 |
| Urban | 1.2 | 1.7 | 2.1 | 1.8 | 2.5 |
| Village | 2.8 | 1.8 | 1.3 | 1.7 | 1.9 |
| Residential | 3.1 | 2.1 | 4.7 | 1.6 | 0.9 |

F=2.2 Err\_K accuracy

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Elevation (°)Environment | 20 | 30 | 45 | 60 | 70 |
| Wooded | 2.7 | 2.5 | 2.0 | 2.6 | 1.5 |
| Suburban | 2.6 | 1.6 | 1.5 | 1.8 | 1.2 |
| Urban | 3.6 | 3.2 | 3.2 | 2.3 | 1.2 |
| Village | 3.2 | 3.0 | 2.5 | 2.6 | 1.4 |
| Residential | 2.4 | 2.5 | 1.3 | 1.1 | 1.2 |

Testing results for f = 3.8 GHz

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Elevation (°)Environment | 20 | 30 | 45 | 60 | 70 |
| Wooded | OK | OK | OK | OK | OK |
| Suburban | OK | OK | OK | OK | OK |
| Urban | OK | OK | OK | OK | OK |
| Village | OK | OK | OK | OK | OK |
| Residential | OK | OK | NOK | OK | OK |

Err\_fm

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Elevation (°)Environment | 20 | 30 | 45 | 60 | 70 |
| Wooded | 0.9 | 1.0 | 1.1 | 1.0 | 0.5 |
| Suburban | 0.6 | 0.9 | 1.3 | 0.3 | 0.2 |
| Urban | 0.9 | 1.1 | 1.9 | 0.7 | 0.7 |
| Village | 1.0 | 1.4 | 1.0 | 0.3 | 0.4 |
| Residential | 1.4 | 0.7 | 2.1 | 0.5 | 0.8 |

Err\_afd

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Elevation (°)Environment | 20 | 30 | 45 | 60 | 70 |
| Wooded | 0.33 | 0.34 | 0.22 | 0.16 | 0.11 |
| Suburban | 0.38 | 0.37 | 0.08 | 0.18 | 0.08 |
| Urban | 1.03 | 0.35 | 0.30 | 0.16 | 0.12 |
| Village | 0.28 | 0.22 | 0.17 | 0.13 | 0.08 |
| Residential | 0.27 | 0.16 | 0.07 | 0.21 | 0.08 |

Err\_K

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Elevation (°)Environment | 20 | 30 | 45 | 60 | 70 |
| Wooded | 2.9 | 3.6 | 2.8 | 3.6 | 3.2 |
| Suburban | 1.7 | 1.4 | 2.6 | 2.7 | 1.2 |
| Urban | 1.4 | 1.6 | 1.9 | 2.8 | 2.1 |
| Village | 1.9 | 1.6 | 2.0 | 2.0 | 2.5 |
| Residential | 2.5 | 1.9 | 4.5 | 2.5 | 2.0 |

Err\_K accuracy

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Elevation (°)Environment | 20 | 30 | 45 | 60 | 70 |
| Wooded | 2.5 | 2.5 | 2.1 | 2.4 | 1.9 |
| Suburban | 1.6 | 2.2 | 0.6 | 1.5 | 1.0 |
| Urban | 2.2 | 2.8 | 2.3 | 1.2 | 1.1 |
| Village | 2.3 | 2.7 | 1.6 | 1.6 | 0.7 |
| Residential | 1.9 | 1.6 | 0.8 | 0.6 | 0.8 |

Testing results for f = 11.7 GHz

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Environment | Err\_fm | Err\_afd | Err\_K | K\_acc |
| Suburban – 34° | 0.5 | 0.51 | 4.3 | 8.8 |
| Rural – 34° | 0.4 | 0.51 | 5.7 | 9.4 |

References

[1] L. J. Greenstein, D.G. Michelson, V. Erceg, “Moment-Method Estimation of the Ricean K-Factor”. IEEE Communications Letters, Vol 3, No. 6, June 1999.

[2] Bezdec J.C., “Pattern Recognition with Fuzzy Objective Function Algorithms”, Plenum Press, New York, 1981.

[3] Montenegro-Villacieros B.: "Versatile two-state model for land mobile satellite systems: parameter extraction and time series synthesis, Ph’D thesis, UCL, Belgium, September 2011.

[4] Pérez Fontán F., Carrie G., Lacoste F., Montenegro Villacieros B., Vanhoenacker-Janvier D., Lemorton J.: "An Enhanced Narrowband Statistical Land Mobile Satellite Channel Model for the S- and C-Bands", ESA workshop on Radiowave propagation 2011, ESTEC, Noordwijk, The Netherlands, 30 November - 2 December 2011.

[5] Carrie G., Pérez Fontán F., Lacoste F., Lemorton J.: "A generative MIMO channel model encompassing single satellite and satellite diversity cases", ESA workshop on Radiowave propagation 2011, ESTEC, Noordwijk, The Netherlands, 30 November - 2 December 2011.

[6] T. Heyn, E. Eberlein, D. Arndt, B. Matuz, F. Lázaro Blasco, R. Prieto-Cerdeira, J. Rivera-Castro, “Mobile Satellite Channel with Angle Diversity: the MiLADY Project”, EuCAP conference, Barcelona, April 2010

[7] S. Scalise, H. Ernst, G. Harles, “Measurement and Modelling of the Land Mobile Satellite Channel at Ku-Band”, IEEE Trans. on Veh. Tech., Vol. 57, No. 2, March 2008

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