Technical Note on the Land Mobile Satellite Channel Model
-
Interface Control Document

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Abstract

This document contains information related to the software implementation of the Land Mobile Multipath Channel Model (LMSCM). It provides a description of the interface implemented in the software. The intention of this document is to allow a user of the software to use other statistical data than the one delivered with this implementation.

Contents

1. Introduction

The statistical data provided with the Land Mobile Multipath Channel Model (LMSCM) was derived from measurement data recorded in a comprehensive high resolution channel sounding campaign in and around Munich in 2002. In this campaign different urban, suburban and rural environments were measured for car and pedestrian applications.

In these measurements the satellite of a potential navigation system was simulated by a Zeppelin NT. The Zeppelin transmitted the measurement signal between 1460 and 1560 MHz towards the ground using a hemispherical, circular polarised, antenna with 10W EIRP. The receiver was mounted in the measurement vehicle, which was driven through the measurement area. In the case of the pedestrian measurement the antenna was carried by the walking user followed by the measurement vehicle.

Based on this measurement data the Land Mobile Multipath Channel Model was developed. This model is a realistic high resolution deterministic-statistical model. A receiver can be moved through an artificial scenery with houses, trees and lamp posts. These obstacles influence the LOS path. In addition reflectors are produced causing echo signals.

The statistical part of the model comprises

- the house front, tree and lamp post generation in the artificial scenery,
- the position dependent LOS signal power variations in the shadow of tree tops,
- the position of reflectors dependent on the satellites azimuth and elevation,
- the mean power of echoes depending on their distance to the receiver and on the
- satellite elevation,
- Rice factor and bandwidth of echo signals depending on the satellite elevation,
- the life span of echoes depending on the satellite elevation,
- the number of coexisting echoes in the channel depending on the satellite elevation,
- and the movement of reflection points, also depending on the satellite elevation.

Deterministically modelled are

- the diffraction of the LOS signal on houses, tree trunks and lamp posts,
- the delay of diffracted signals received in the shadow of houses,
- the mean attenuation through tree tops,
- and the delay and Doppler shift trends of echo signals due to the receiver and reflector movement.

An important model feature is the high level of detail. Realistic correlation between echo signals is achieved due to the used reflector position statistics combined with the deterministically calculated delay and Doppler trends. Full satellite azimuth and elevation dependency is given for both LOS and the echo signals. As general model parameters the snapshot rate, the frequency band, the user type and the environment can be chosen.

Parameters for the distribution of e.g. house heights and widths, for tree and lamp post size and positions, but also for the street width and e.g. the receiver antenna height allow to model specific scenarios and to investigate their impact. High flexibility is also given by the way oriented deterministic and stochastic model approach. Receiver speed and heading input allows to simulate different movement situations, e.g. turns, a traffic jam, stop and go, or the relatively long stops at traffic lights. Also speeds which are even higher than during the measurement can be applied.

The MATLAB implementation of the model needs only 140 kBytes disk space including the statistic data for the urban city center environment for car applications. It is a stand alone model generating its own scenery. The execution speed is reasonably fast with 250 complex channel impulse responses per second on a 1.5GHz CPU. The model output is a complex time-variant channel impulse response with up to 80 discrete rays. Due to this time variant tapped delay line structure it can be easily incorporated in any simulator.

For a complete description of the measurement, the data analysis and the modelling of the satellite to earth multipath channel we refer to [1].

2. Statistical data file description

With the channel model implementation, two Matlab files which contain statistical channel data, are provided for different environments (urban, suburban) and different applications (car, pedestrian).

As example for car applications in an urban environment the statistical data files are named `EchoNumberParUrbanCar.mat` and `EchoParUrbanCar.mat`.

These two data files contain the following lists of Matlab variables:

`EchoNumberParUrbanCar.mat`

Name	Size	Bytes	Class
ANraysCumSpecFreqBins	32x9	2304	double
ANraysCumSpecVal	32x9	2304	double
ANraysMean	1x9	72	double
ElevationVec	1x9	72	double

`EchoParUrbanCar.mat`

Name	Size	Bytes	Class
ABandwidthMean	1x9	72	double
ABandwidthSigma	1x9	72	double
ADeltaAzim	10x9	720	double
ALengthCdfBins	24x9	1728	double
ALengthCdfValues	24x9	1728	double
AMeanPower	10x10x9	7200	double
AMeanPowerSigma	10x10x9	7200	double
APosition	10x10x9	7200	double
ARfxMovProb	1x9	72	double
ARiceCdfBins	27x9	1944	double
ARiceCdfValues	27x9	1944	double
ElevationVec	1x9	72	double

2.1. Elevation vector

Different statistical channel parameters are stored in these variables. The last dimension of each variable is related to the satellite elevation, which is the angle between the tangential plane of the earth's surface at the user position and the incidence angle of the direct path signal from the satellite. Basis for the statistics are channel measurements at nine different elevations. These values are stored in the variable `ElevationVec` in degrees:

```
ElevationVec =

     5    10    20    30    40    50    60    70    80
```

2.2. Number of coexisting echoes

In the measurements a narrow and a wide band process were identified causing variations in the number of coexisting echoes as the receiver moves through the multipath environment. To model the receiver position dependent variations in the number of coexisting echoes $N_e(x)$, where x is the receiver's position along its trajectory, both processes are synthesized in the implemented channel model.

The discrete common CDF (Cumulative Distribution Function) of the narrow and wide band process is approximated by a piecewise linear function $P(X)$, which is stored in the variables `ANraysCumSpecVal` and `ANraysCumSpecFreqBins` for the nine different elevations.

As example the values of the CDF with unit [1] for 5° elevation are:

```
ANraysCumSpecVal(:,1)' =

  1.0e+006 *

0    0.4294    0.4897    0.4970    0.5587    0.6614    0.7495
0.7734    0.7771    0.7795    0.7891    0.7911    0.7978
0.8025    0.8041    0.8138    0.8294    0.8440    0.8696
0.8841    0.9148    0.9805    1.0429    1.0813    1.1017
1.1160    1.1258    1.1431    1.1505    1.1555    1.1600
1.1627

at the corresponding spatial frequencies with unit [1/m]
stored in

ANraysCumSpecFreqBins(:,1)' =

0    0.0005    0.0010    0.0015    0.0020    0.0025    0.0030
0.0035    0.0040    0.0045    0.0055    0.0065    0.0075
0.0085    0.0095    0.0120    0.0145    0.0195    0.0345
```

```
0.0495    0.0995    0.2495    0.4995    0.7495    0.9995
1.2495    1.4995    2.4995    3.4995    4.9995    7.4995
9.9995
```

Figure 1 shows all CDF's of the receiver position dependent narrow and wide band process of the change in the number of coexisting echoes for the urban car channel.

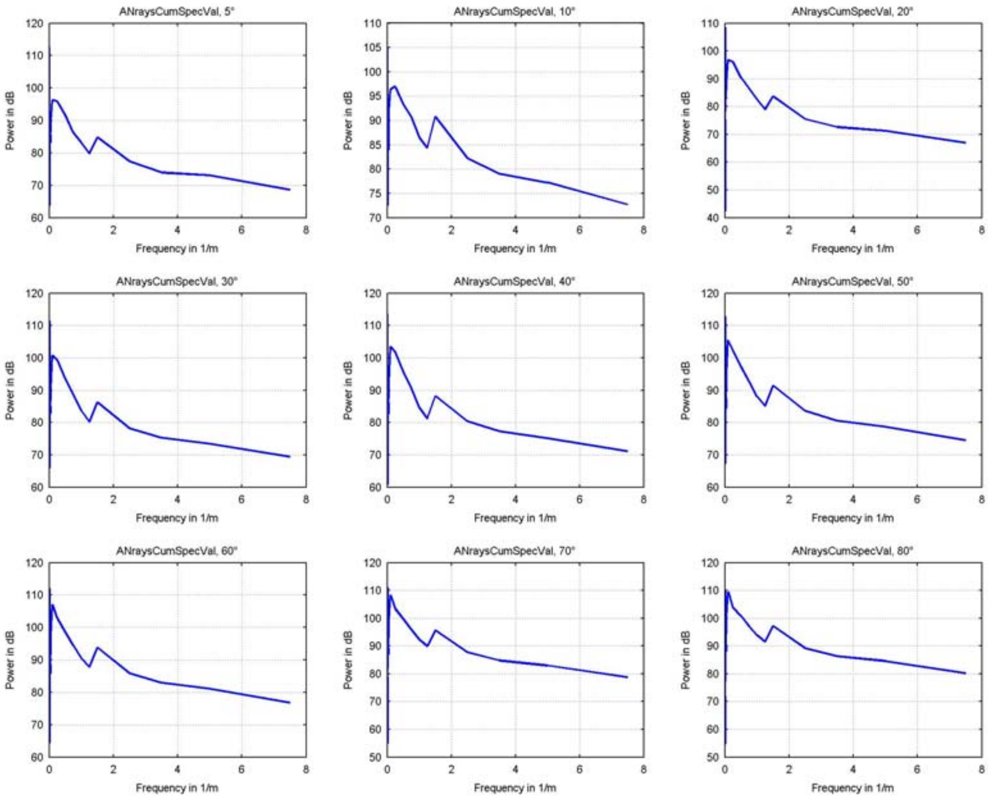

Figure 1: CDF of the receiver position dependent narrow and wide band process of the change in the number of coexisting echoes – urban car channel

In the channel model the spectrum of the process is derived from the CDF *P(X)* by differentiation. Next an inverse Fourier transform is calculated resulting in the synthesized change of the number of coexisting echoes $N_p(x)$. The total number of coexisting echoes is calculated by adding the average number of echoes $\bar{n}$ with a lower bound of zero:

$$N_e(x) = \max(0, N_p(x) + \bar{n})$$

The average number of coexisting echoes $\bar{n}$ is stored in the variable `ANraysMean`. As example, the values for the different elevations in the urban environment for car applications are:

```
ANraysMean =
```

```
  8.7311   13.0396   13.2762   18.3764   23.4766   24.6038
25.7309   26.8581   27.9853
```

Figure 2 shows the average number of coexisting echoes as function of the elevation.

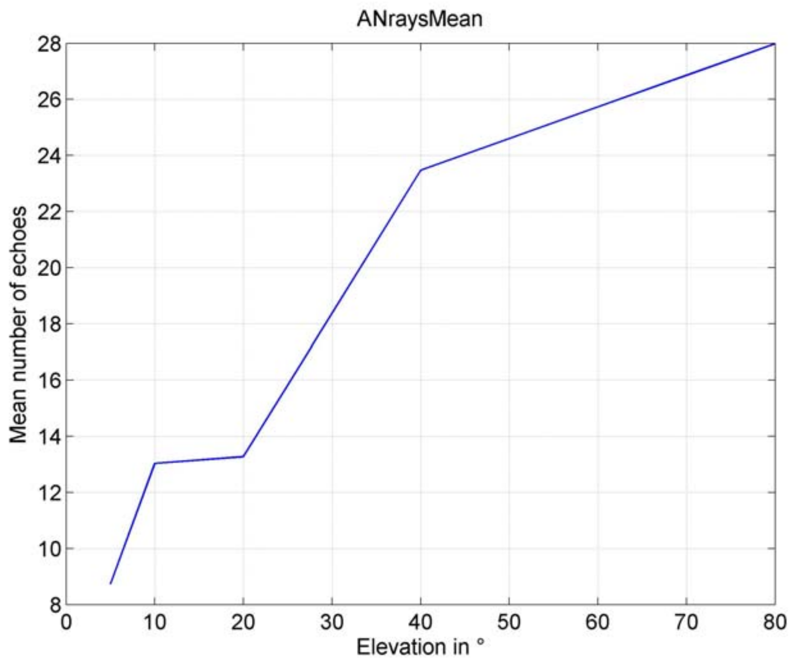

Figure 2: Average number of coexisting echoes – urban car channel

2.3. Echo bandwidth

In the implemented model the distribution of the echoes' bandwidth is modelled by a Gaussian process. The corresponding mean and variance values in Hz are stored in the variables `ABandwidthMean` and `ABandwidthSigma` for the different elevations. Again for the urban car example these values are

```
ABandwidthMean =

4.6770    4.6874    4.6990    4.7520    4.8049    4.7791
4.7533    4.7275    4.7017
```

and

```
ABandwidthSigma =

2.0850    2.0817    2.0652    2.0271    1.9889    1.9829
1.9769    1.9709    1.9649
```

Figure 3 and Figure 4 show the mean and variance of the echo bandwidth as function of the elevation for the urban car channel.

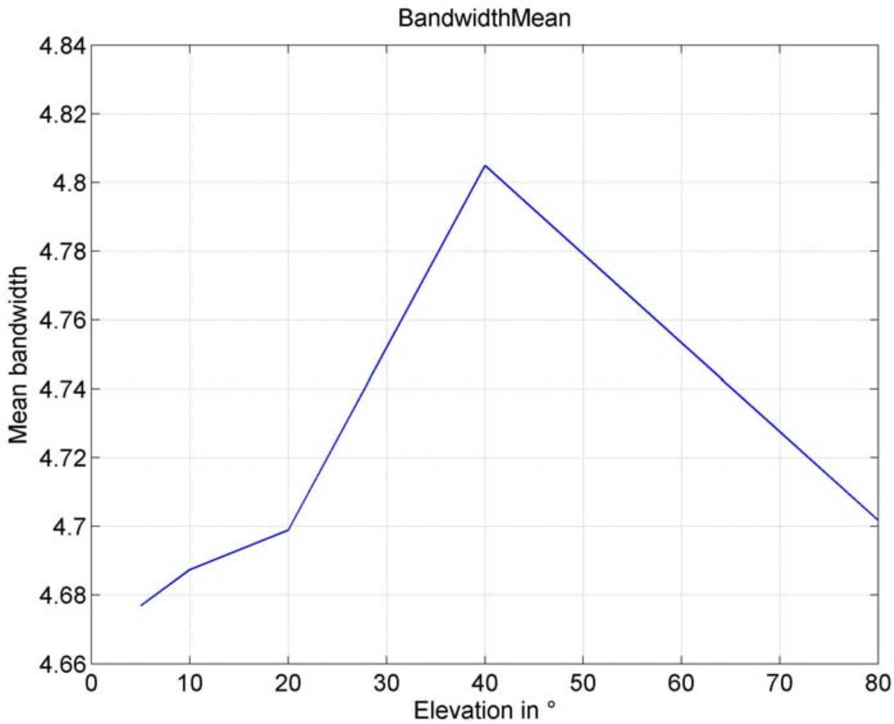

Figure 3: Reflector bandwidth mean – urban car channel

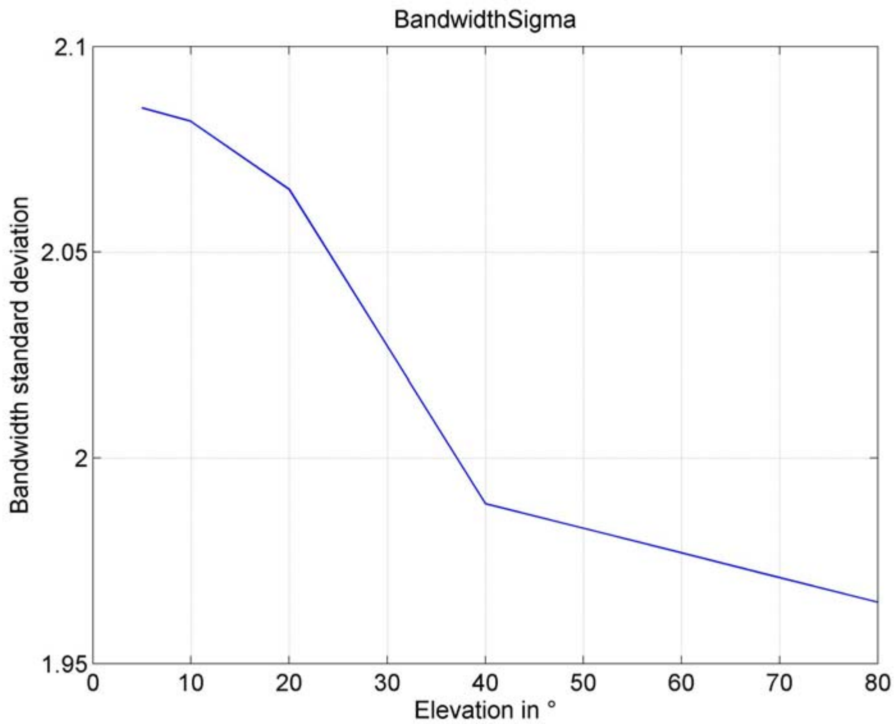

Figure 4: Reflector bandwidth sigma – urban car channel

2.4. Life span of reflectors

In the measurement data the channel appears rapidly changing. Many echoes disappear and new ones appear. This process is highly correlated to the receiver speed. When the receiver stops, the echoes remain. In order to allow the motion dependent modelling of the multipath channel, the echo life span in meters is defined. This life span is the distance the receiver is travelling from appearance of an echo until it disappears.

The discrete distribution of the life span of reflectors, respectively its CDF, is stored in the variables `ALengthCdfBins` and `ALengthCdfValues`, where for example

```
ALengthCdfValues(:,1)' =

0    0.2776    0.4758    0.6044    0.6934    0.7568    0.8030
0.8373    0.8637    0.8844    0.9144    0.9348    0.9492
0.9598    0.9675    0.9798    0.9866    0.9934    0.9963
0.9977    0.9990    0.9994    0.9999    1.0000
```

are the values at the lowest elevation of 5° at the corresponding life spans in meters:

```
ALengthCdfBins(:,1)' =

0.1000    0.2000    0.3000    0.4000    0.5000    0.6000
0.7000    0.8000    0.9000    1.0000    1.2000    1.4000
1.6000    1.8000    2.0000    2.5000    3.0000    4.0000
5.0000    6.0000    8.0000   10.0000   15.0000   20.0000
```

The CDF's of the life span of reflectors in the urban car environment are illustrated in Figure 5.

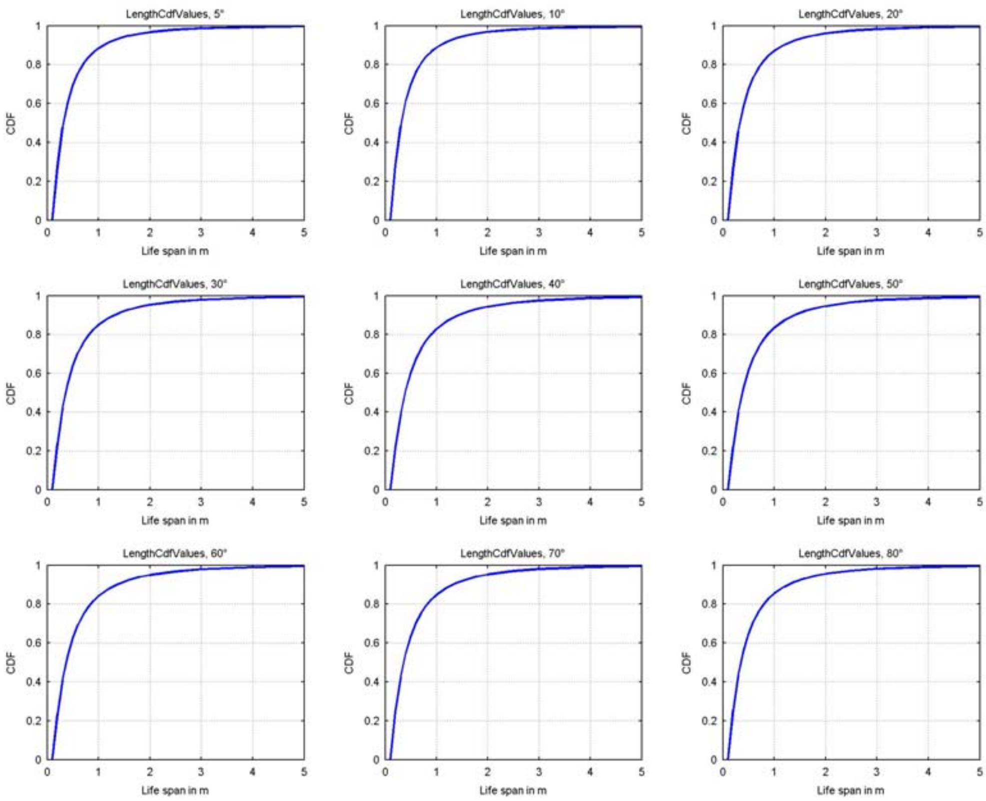

Figure 5: Life span of reflectors CDF – urban car channel

2.5. Rice factor of echoes

The fading characteristic of single echo signals observed in the measured data indicates a constant component. Therefore a Rician model is applied. The discrete distribution of the Rice factors of echo signals, respectively its CDF, is stored in the variables `ARiceCdfBins` and `ARiceCdfValues`, where for example

```
ARiceCdfValues(:,1)' =

0      0.0058    0.0138    0.0220    0.0313    0.0422    0.0542
0.0672    0.0810    0.0955    0.1255    0.1561    0.1864
0.2161    0.2448    0.3109    0.3686    0.4645    0.5412
0.6027    0.6937    0.7579    0.8538    0.9042    0.9553
0.9799    1.0000
```

are the values at the lowest elevation of 5° at the corresponding Rice factor bins

```
ARiceCdfBins(:,1)' =
```

0.1000	0.2000	0.3000	0.4000	0.5000	0.6000
0.7000	0.8000	0.9000	1.0000	1.2000	1.4000
1.6000	1.8000	2.0000	2.5000	3.0000	4.0000
5.0000	6.0000	8.0000	10.0000	15.0000	20.0000
30.0000	40.0000	60.0000			

The CDF's of the Rice factor of echo signals in the urban car environment are illustrated in Figure 6.

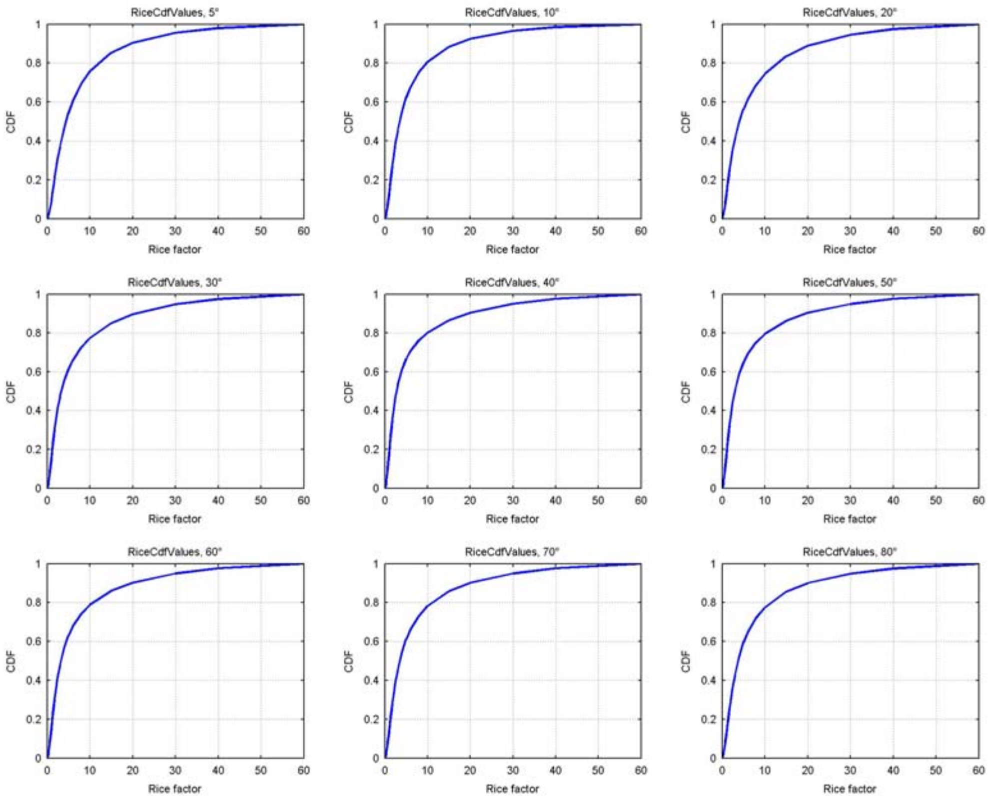

Figure 6: Rice factor of echo signals CDF – urban car channel

2.6. Movement of reflection points

The measurements also revealed that some reflection points move according to the movement of the receiver (like e.g. on a house wall), while others remain at fixed positions. A measure for this behaviour is the observed change in the angle α, which is the angle between the van's moving direction and the direction to the reflection point. For a theoretically fixed reflection α would change according to the movement of the receiver. On the other hand, if the reflection point moves e.g. along a house front, α does not change during the observation interval. The distribution of this angular changes shows a significant bend, which allows to estimate the percentage of reflection points which are moving. The rest can be associated with fixed reflectors, e.g. traffic signs or trees, which in general have very short life spans.

The probabilities for a moving reflection point at different elevations are stored in

```
ARfxMovProb =

0.0209    0.0387    0.0559    0.1386    0.1471    0.1536
0.1600    0.1665    0.1730
```

and are plotted in Figure 7.

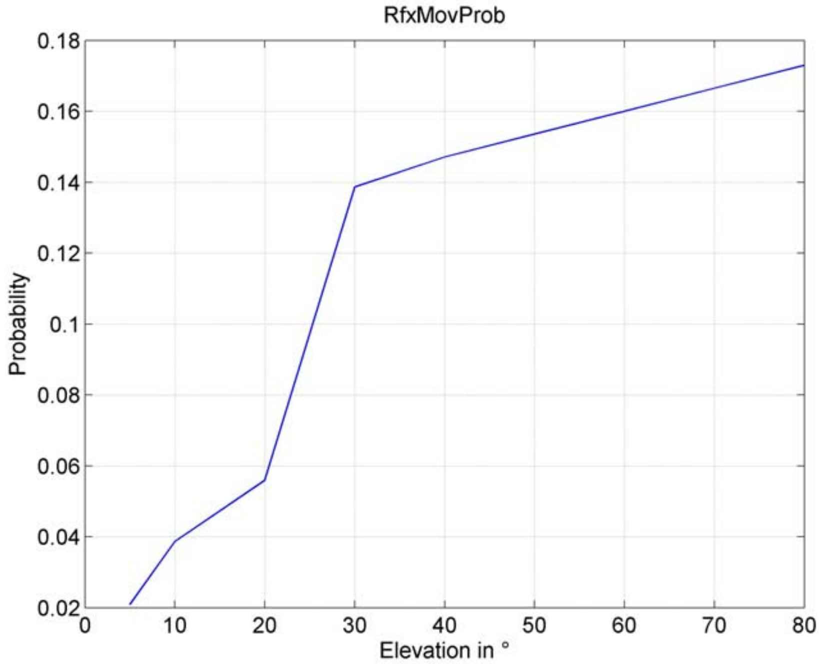

Figure 7: Reflector movement probability – urban car channel

2.7. Horizontal reflector position distribution

Further analysis of the measurement data show, that the horizontal position distribution of reflectors relative to the receiver position changes significantly for different elevations. These two-dimensional distributions are symmetrical with respect to the movement direction of the receiver, because in urban and suburban environments the likelihood for a reflector to be on the left or the right side of a street is the same. Moreover, the likelihood for a reflector in front or in the rear is the same, thus the distributions are symmetrical with respect to the cross axis, too. Hence, only a quarter of the distributions needs to be stored.

The two step polynomial approximations of these horizontal reflector position distributions are stored in the variable `APosition`.

As an example the polynomial coefficients for 5° elevation in the urban car case are:

```
APosition(:,:,1) =

  Columns 1 through 4

 -4.2762e-038  8.4117e-035 -6.9855e-032  3.1800e-029
  1.9300e-035 -3.7787e-032  3.1218e-029 -1.4130e-026
 -3.6100e-033  7.0363e-030 -5.7842e-027  2.6030e-024
  3.6015e-031 -6.9922e-028  5.7219e-025 -2.5610e-022
 -2.0482e-029  3.9650e-026 -3.2331e-023  1.4405e-020
  6.5416e-028 -1.2655e-024  1.0305e-021 -4.5796e-019
 -1.0705e-026  2.0804e-023 -1.7004e-020  7.5746e-018
  7.3129e-026 -1.4463e-022  1.2015e-019 -5.4257e-017
 -6.1199e-026  1.3699e-022 -1.2466e-019  5.9536e-017
  4.5639e-025 -9.4822e-022  8.3410e-019 -4.0362e-016

  Columns 5 through 8

 -8.6107e-027  1.4025e-024 -1.3089e-022  5.9626e-021
  3.8008e-024 -6.1448e-022  5.6899e-020 -2.5789e-018
 -6.9548e-022  1.1153e-019 -1.0229e-017  4.5915e-016
  6.7969e-020 -1.0807e-017  9.7998e-016 -4.3308e-014
 -3.7995e-018  5.9880e-016 -5.3581e-014  2.3133e-012
  1.2024e-016 -1.8796e-014  1.6558e-012 -6.9005e-011
 -1.9881e-015  3.0896e-013 -2.6721e-011  1.0509e-009
  1.4368e-014 -2.2300e-012  1.8771e-010 -6.5134e-009
 -1.5862e-014  2.2390e-012 -1.1857e-010 -5.9136e-009
  1.1683e-013 -2.0590e-011  2.1473e-009 -1.2071e-007

  Columns 9 through 10

 -6.7635e-020 -8.6843e-019
  3.0199e-017  3.4464e-016
 -5.3951e-015 -5.9065e-014
  4.9353e-013  5.7003e-012
 -2.4271e-011 -3.3547e-010
  5.9928e-010  1.2058e-008
 -5.2603e-009 -2.5004e-007
 -3.0846e-008  2.7240e-006
  7.7678e-007 -1.2097e-005
  2.6144e-006  3.7349e-005
```

In the model a quarter of the horizontal reflector position distribution in polar coordinates is calculated from these coefficients by

```
for r = 1:length(RadiusVec)
     p = diag(APosition(:,:,k)*repmat([RadiusVec(r).^[9:-
1:0]],11,1)');
     y = polyval(p(1:10),AzimuthVec,9);
     A(:,r) = y';               % Quarter of position distribution
end
```

where *k* is the index of the elevation and

```
RadiusVec = [0:2:250];         % Model radius grid in m
AzimuthVec = [0:2:90];         % Model azimuth grid in degrees
```

Figure 8 shows the full map of the horizontal reflector position distributions. The x-axis is the moving direction of the receiver along a street.

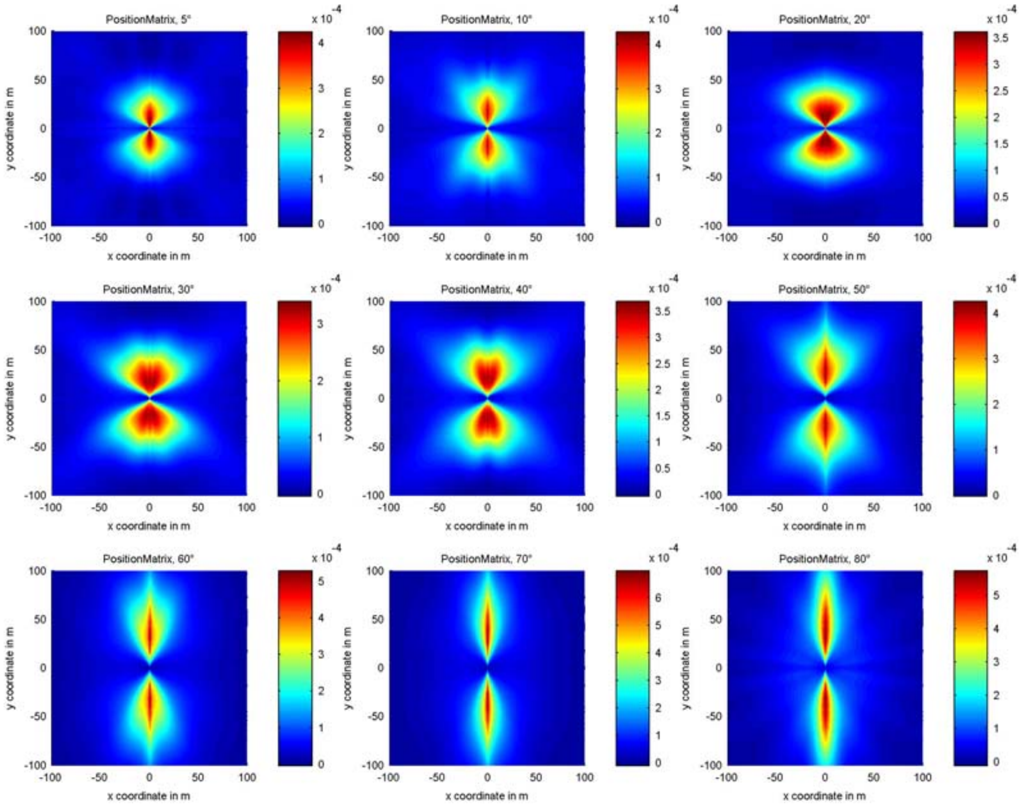

Figure 8: Horizontal reflector position distribution – urban car channel

2.8. The relative satellite-reflector azimuth angle

The above described horizontal reflector position distributions are independent of the satellite azimuth. In order to model the multipath channel dependent on both satellite elevation and azimuth, statistics for the azimuthal angle of arrival of echoes relative to the LOS signal are used. As the measurements revealed these distributions are symmetrical for positive and negative angles.

Polynomial approximations of these statistics between 0-180° (because of the symmetry) are stored in the variable `ADeltaAzim` for the different elevation angles. As example for 5° elevation in the urban car case the polynomial coefficients are

```
ADeltaAzim(:,1)' =

-6.6625e-020  5.8308e-017 -2.1039e-014  4.0321e-012 -4.4015e-
010   2.7190e-008 -8.8648e-007  1.3628e-005 -6.6625e-005
9.9306e-004
```

In the model the relative satellite-reflector azimuth angle distribution is calculated from these coefficients by

```
A = polyval(ADeltaAzim(:,k),DeltaAzimuthVec,9);
Afull = [A,A(end-1:-1:1)];   % Full delta azimuth distribution
```

where *k* is the index of the elevation and

```
DeltaAzimuthVec = [0:2:180]; % Model delta azimuth grid in
degrees
```

Figure 9 shows the relative satellite-reflector azimuth angle distribution for different elevations for car applications in urban environments.

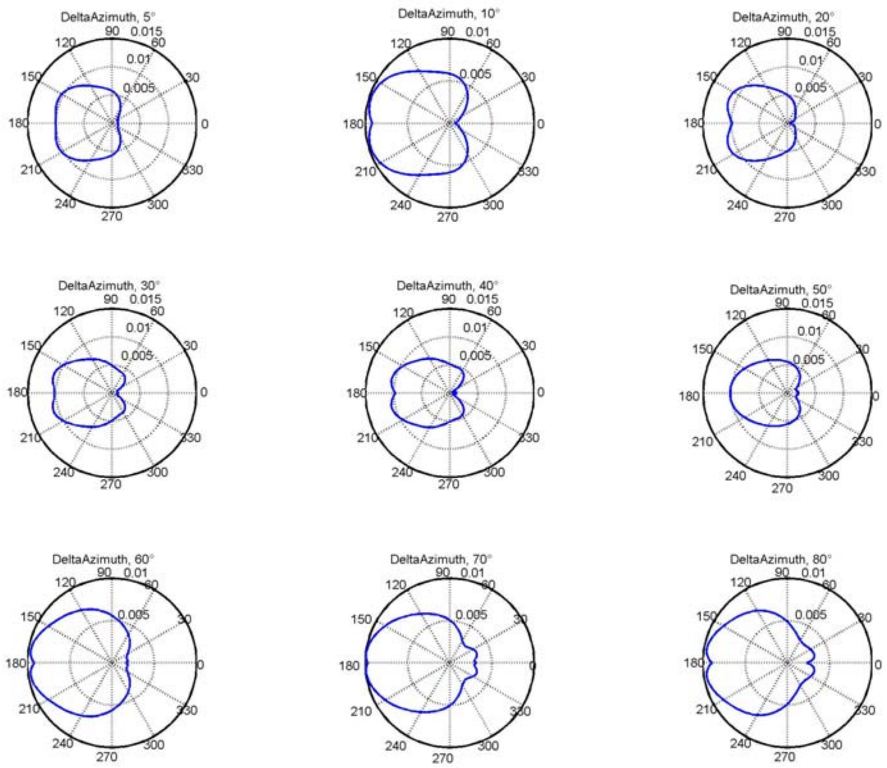

Figure 9: Relative satellite-reflector azimuth angle distribution – urban car channel

2.9. Average power of echo signals

The distance and direction of a reflector from the receiver plays a major role for the power of the received echo signal. This fact is taken into account in the LMS channel model. From the measurement data statistics for the mean and for the standard deviation of the average echo power depending on the relative horizontal reflector position were determined. Again these two-dimensional distributions are symmetrical with respect to the movement direction of the receiver and with respect to the cross axis. Hence, only a quarter of the distributions needs to be stored.

The two step polynomial approximations of mean and variance of these echo power distributions are stored in the variables `AMeanPower` and `AMeanPowerSigma`, respectively. The mean and variance values of these distributions are giving the echo powers in dB relative to an unobstructed direct path signal.

```
AMeanPower(:,:,1) =

  Columns 1 through 4

  3.2415e-033 -4.4259e-030  2.0915e-027 -2.4915e-025
```

```
 -1.4516e-030  2.0161e-027 -9.8989e-025  1.4582e-022
  2.6687e-028 -3.7401e-025  1.8708e-022 -2.9970e-020
 -2.5852e-026  3.6192e-023 -1.8021e-020  2.8107e-018
  1.3999e-024 -1.9254e-021  9.1711e-019 -1.1130e-016
 -4.0648e-023  5.2756e-020 -2.1378e-017 -3.5833e-016
  4.9848e-022 -4.9793e-019  1.5104e-017  1.7251e-013
  1.2194e-021 -6.0663e-018  8.0632e-015 -5.0351e-012
 -6.4724e-020  1.2835e-016 -1.0736e-013  4.9239e-011
  1.1131e-019 -1.7655e-016  1.1110e-013 -3.4615e-011

  Columns 5 through 8

 -1.1925e-022  5.0124e-020 -7.8214e-018  5.5650e-016
  4.1637e-020 -2.0094e-017  3.2257e-015 -2.3139e-013
 -6.5995e-018  3.4849e-015 -5.6760e-013  4.0781e-011
  6.7858e-016 -3.4584e-013  5.5772e-011 -3.9715e-009
 -5.1674e-014  2.1765e-011 -3.3575e-009  2.3344e-007
  2.7945e-012 -8.9493e-010  1.2720e-007 -8.4755e-006
 -9.4727e-011  2.3281e-008 -2.9617e-006  1.8540e-004
  1.7310e-009 -3.4324e-007  3.8525e-005 -2.2248e-003
 -1.3471e-008  2.2365e-006 -2.1816e-004  1.1296e-002
  5.2379e-009 -2.3587e-007 -2.8721e-005  3.6428e-003

  Columns 9 through 10

 -1.4925e-014  1.0488e-013
  6.1936e-012 -4.3351e-011
 -1.0852e-009  7.5583e-009
  1.0450e-007 -7.2361e-007
 -6.0306e-006  4.1483e-005
  2.1307e-004 -1.4548e-003
 -4.4920e-003  3.0403e-002
  5.1368e-002 -3.4283e-001
 -2.4106e-001  1.5657e+000
 -1.4033e-001 -3.0032e+001

AMeanPowerSigma(:,:,1) =

  Columns 1 through 4

 -6.7162e-036 -1.3427e-031  2.5678e-028 -1.9790e-025
  2.8474e-032  8.2478e-030 -6.9534e-026  6.6278e-023
 -1.0421e-029  8.8194e-027  3.9699e-024 -7.9929e-021
  1.6298e-027 -2.0585e-024  6.0874e-022  3.2146e-019
 -1.3599e-025  2.0158e-022 -1.0457e-019  1.3616e-017
  6.4285e-024 -1.0401e-020  6.5078e-018 -1.8134e-015
 -1.7047e-022  2.9095e-019 -1.9957e-016  6.8149e-014
  2.3556e-021 -4.1320e-018  2.9566e-015 -1.0897e-012
 -1.4295e-020  2.4816e-017 -1.7517e-014  6.3391e-012
```

```
  5.5300e-020 -9.8571e-017  7.2827e-014 -2.8728e-011

  Columns 5 through 8

  8.1771e-023 -1.9705e-020  2.8014e-018 -2.2505e-016
 -2.9883e-020  7.5472e-018 -1.1046e-015  9.0513e-014
  4.2796e-018 -1.1681e-015  1.7878e-013 -1.5090e-011
 -2.9039e-016  9.2293e-014 -1.5227e-011  1.3459e-009
  7.8105e-015 -3.8059e-012  7.2537e-010 -6.9179e-008
  1.0264e-013  6.8814e-011 -1.8867e-008  2.0593e-006
 -1.0763e-011  5.6750e-011  2.4039e-007 -3.4208e-005
  2.0843e-010 -1.4956e-008 -1.3074e-006  3.0631e-004
 -1.1794e-009  7.9272e-008  7.7429e-006 -1.6358e-003
  6.4736e-009 -8.1970e-007  5.1574e-005 -8.2620e-004

  Columns 9 through 10

  8.9018e-015 -9.8528e-014
 -3.6356e-012  4.1189e-011
  6.1957e-010 -7.2226e-009
 -5.7064e-008  6.8914e-007
  3.0750e-006 -3.8804e-005
 -9.8162e-005  1.3070e-003
  1.7996e-003 -2.5461e-002
 -1.7782e-002  2.6351e-001
  8.7924e-002 -1.2001e+000
 -6.2491e-002  3.3190e+000
```

In the model a quarter of the mean and variance echo power distribution in polar coordinates is calculated from these coefficients by

```
for r = 1:length(RadiusVec)
     p = diag(AMeanPower(:,:,k)*repmat([RadiusVec(r).^[9:-
1:0]],11,1)');
     y = polyval(p(1:10),AzimuthVec,9);
     Pm(:,r) = y';       % Quarter of power distribution mean
     p = diag(AMeanPowerSigma(:,:,k)*repmat([RadiusVec(r).^[9:-
1:0]],11,1)');
     y = polyval(p(1:10),AzimuthVec,9);
     Ps(:,r) = y';       % Quarter of power distribution sigma
end
```

where *k* is the index of the elevation and

```
RadiusVec = [0:2:250];   % Model radius grid in m
AzimuthVec = [0:2:90];   % Model azimuth grid in degrees
```

Figure 10 and Figure 11 show the full map of the mean and variance distributions.

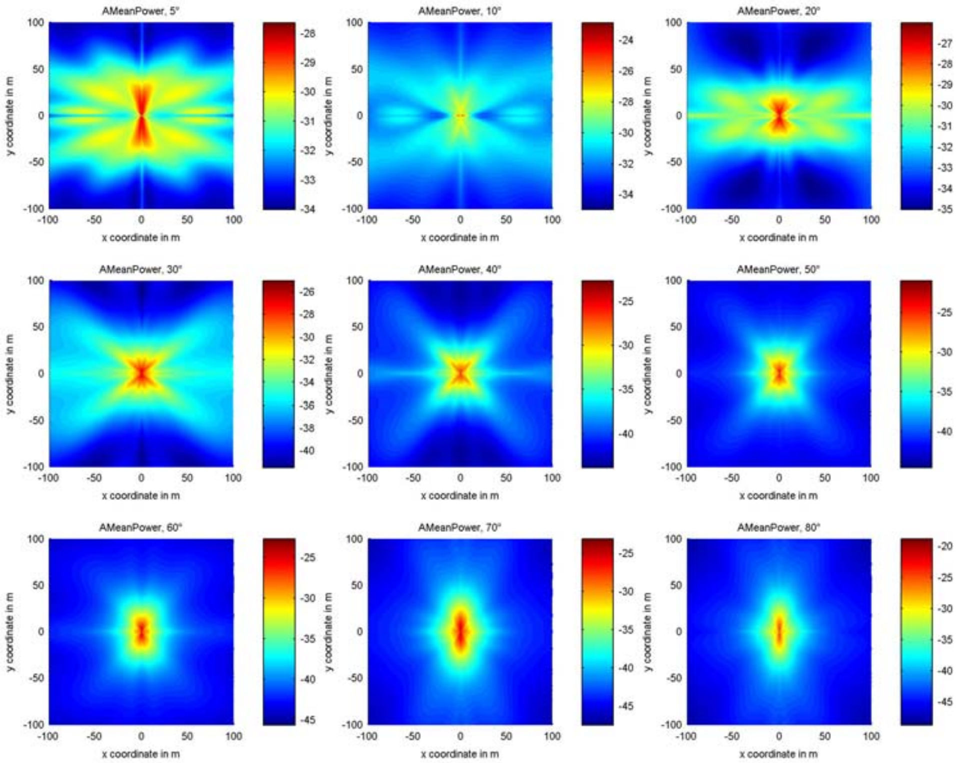

Figure 10: Echo power distribution mean – urban car channel

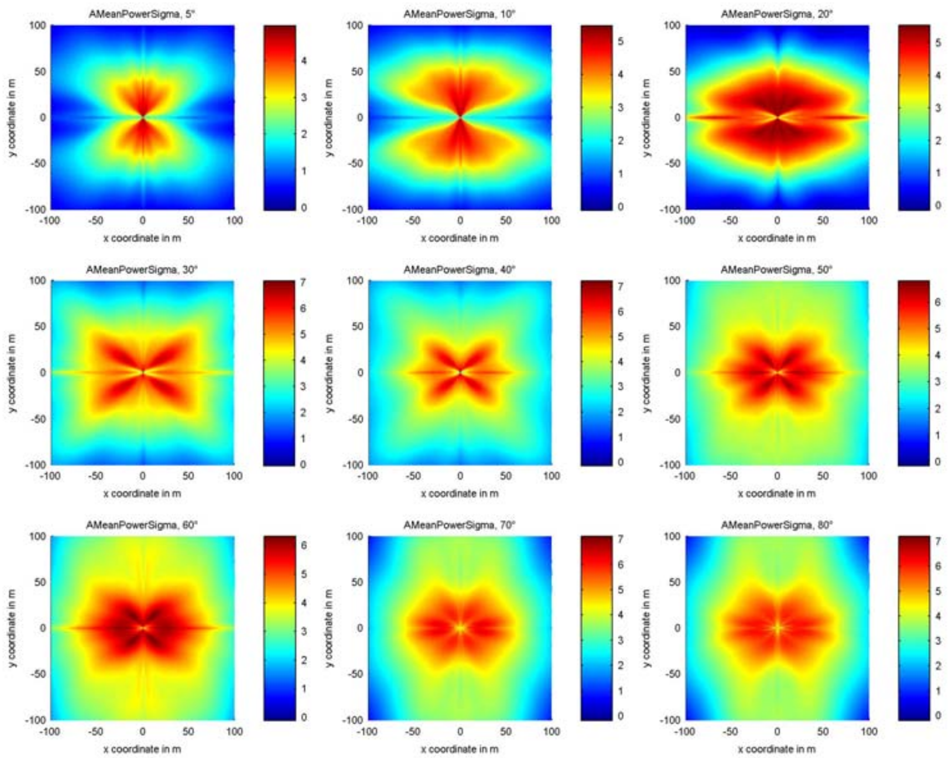

Figure 11: Echo power distribution sigma – urban car channel

3. References

[1] Andreas Lehner, "Multipath Channel Modelling for Satellite Navigation Systems”, PhD Thesis, University of Erlangen-Nuremberg, ISBN 978-3-8322-6651-6, Shaker Verlag GmbH, D-52018 Aachen, Germany, 2007.

4. List of Figures

5. Acronyms

CDF	Cumulative Distribution Function
LMSCM	Land Mobile Satellite Channel Model
LOS	Line-of-sight