3D channel emulation in a multi-probe setup

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A technique to emulate 3D geometry-based channel models in a multi-probe over the air test setup is presented. The proposed technique provides a general emulation framework for any spherical incoming power spectrum. The emulation method results in two optimization objectives, which are both convex. They give optimal emulation accuracy and allow relatively low computational complexity.

Introduction: As a solution to evaluate multiple input multiple output (MIMO) device performance in realistic conditions in the lab, MIMO over the air (OTA) testing has attracted huge interest from both industry and academia, see e.g. [1]. One promising candidate is the multi-probe based anechoic chamber method. Several papers have discussed OTA testing setups for MIMO devices with emphasis on channel modeling, where the goal is to accurately reproduce realistic 2D channels in the test area with a limited number of OTA probes [1]. However, the 2D channel model is not generally valid. Measurements have demonstrated that elevation spread cannot be ignored in many propagation environments, see e.g. [2, 3], and thus emulation of 3D models is required. Very few contributions have addressed this issue. In [4], it was briefly mentioned that probes in a 3D setup were used to emulate 3D channel models, but no algorithm description is given. The 3D channel emulation technique has also been implemented in a commercial channel emulator, the Elektrobit Propsim F8, where the Laplacian distributions are defined for the power azimuth spectrum (PAS) and the power elevation spectrum (PES). However, a description of the implemented channel emulation algorithm is not available. This letter presents a new channel emulation technique for arbitrary 3D channel models.

Method: The modeling of radio channel parameters such as delay, Doppler, channel polarization and transmitter (Tx) side spatial correlation can be treated individually and hence explained for any one polarization. It itself will assume some DUT antennas if antenna patterns are otherwise limited. Based on the assumption about the isotropic antenna pattern of antennas \(a\) and \(v\), respectively, with a common phase center. Based on the assumption about the isotropic antenna pattern, we can rewrite equation (2) as:

\[
ρ = \frac{1}{4\pi} \exp\left(j k (\mathbf{r}_a - \mathbf{r}_v) \cdot \mathbf{Φ}ight) p(\mathbf{Φ}) d\mathbf{Φ},
\]

where \(\mathbf{r}_a\) and \(\mathbf{r}_v\) are vectors containing the position information of antenna \(a\) and \(v\), respectively. \(\mathbf{Π}\) is an unit vector corresponding to space angle \(\mathbf{Φ}\).

The goal is to obtain OTA probe power weights which minimize the deviation between the theoretical spatial correlation of the target continuous SPS, and the emulated correlation of the discrete SPS characterized by power weights of the probes. Similar to (3), the emulated spatial correlation can be calculated based on the discrete spherical power spectrum characterized by \(M\) probes as:

\[
\hat{ρ} = \sum_{m=1}^{M} w_m \exp\left(j k (\mathbf{r}_m - \mathbf{r}_v) \cdot \mathbf{Π}_m\right),
\]

where \(w_m\) is the power weight for the \(m\)th probe. \(\mathbf{Π}_m\) is a unit position vector of the \(m\)th probe. \(M\) is the number of probes. We will discuss two objective functions:

- Minimize the summation over the total emulation error (Min-Sum):

\[
\min_{w} \| \hat{ρ}(w) - ρ \|_2^2
\]

s.t.

\[
0 \leq w_m \leq 1, \forall m \in [1, M]
\]

which is the wave number. \((\cdot)\) is the dot product operator.

Different ways to sample the test volume: On line segments (squares) and on the surface of an ellipsoid (dots).

- Minimize the maximum emulation error (Min-Max):

\[
\min_{w} \max_{i} |ρ_i(w) - ρ_i|
\]

s.t.

\[
0 \leq w_m \leq 1, \forall m \in [1, M]
\]

Through this objective function unacceptable high emulation errors are avoided, at the expense of larger total emulation error \(\| \hat{ρ}(w) - ρ \|_2^2\), as demonstrated below.

Fig. 1 Different ways to sample the test volume: On line segments (squares) and on the surface of an ellipsoid (dots).

Simulation results and discussions: An example target channel is considered with an azimuth angle of arrival (AoA) = 0° and azimuth spread of arrival (ASA) = 35° defined for the Laplacian shaped PAS; the elevation angle of arrival (EoA) = 15° and elevation spread of arrival (ESA) = 10° for the Laplacian shaped PES. Three different probe configurations are assessed for the target SPS, as detailed in Table 1. The probes are placed on
Table 1: Probe configurations. Value in () denotes the number of probes.

<table>
<thead>
<tr>
<th>Case</th>
<th>Probe Setup</th>
<th>Test volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (16)</td>
<td>(a_1 = 0^\circ, a_2 = -180^\circ + \cdot \cdot \cdot 30^\circ, i \in [1 \ldots 4])</td>
<td>major axis: 0.8(\lambda), minor axis: 0.9(\lambda)</td>
</tr>
<tr>
<td>B (32)</td>
<td>(a_1 = 0^\circ, a_2 = -180^\circ + \cdot \cdot \cdot 45^\circ, i \in [1 \ldots 8])</td>
<td>major axis: 1.8(\lambda), minor axis: 0.9(\lambda)</td>
</tr>
<tr>
<td>C (48)</td>
<td>(a_1 = 0^\circ, a_2 = -180^\circ + \cdot \cdot \cdot 30^\circ, i \in [1 \ldots 12])</td>
<td>major axis: 3(\lambda), minor axis: 0.9(\lambda)</td>
</tr>
</tbody>
</table>

Table 2: Statistics of the emulation results \(|\rho - \hat{|\rho}|\)

<table>
<thead>
<tr>
<th>Case</th>
<th>Channel emulator</th>
<th>Min-Sum</th>
<th>Min-Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>rms 0.07</td>
<td>max 0.16</td>
<td>rms 0.23</td>
</tr>
<tr>
<td>B</td>
<td>rms 0.07</td>
<td>max 0.19</td>
<td>rms 0.18</td>
</tr>
<tr>
<td>C</td>
<td>rms 0.07</td>
<td>max 0.21</td>
<td>rms 0.14</td>
</tr>
</tbody>
</table>

a sphere, and the elevation angle \(\theta\) and the azimuth angle \(\phi\) are specified for each probe. The probes are organized on three elevation rings. \(\theta_j\) denotes the elevation angle for all the probes on \(j\)th elevation ring. \(\phi_{i,j}\) is the azimuth angle of the \(i,j\)th probe on the \(j\)th elevation ring. The test volume is larger for case C than case A due to the larger number of probes.

The target spatial correlation \(|\rho|\) for case C and emulation results with different algorithms are shown in Figure 2. The spatial correlation between the antennas on the surface of the test volume varies with locations of \(u\) and \(v\). Statistics of the emulation results for all cases with different algorithms are summarized in Table 2. Generally, the Min-Sum algorithm presents the best performance for all scenarios in terms of rms error, while the Min-Max algorithm offers the smallest maximal error for all cases, as expected.

Target spatial correlations \(|\rho|\) between antenna \(u\) and \(v\) and emulated spatial correlations \(|\hat{\rho}|\) on two orthogonal axes (azimuth plane) for 3 cases are shown in Fig 3. A clear relation between the test volume and number of probes is shown.

Conclusion: This letter presents a channel emulation technique for 3D geometry-based channel models for a multi-probe based setup. The proposed methods provide a general emulation framework for all spherical power spectrums and offers globally optimal emulation accuracy with low computational complexity.

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References

Fig. 2 Target spatial correlation \(|\rho|\) between antenna \(u\) and \(v\) on the surface of the test volume and the associated emulation results \(|\rho - \hat{\rho}|\).

Fig. 3 Target spatial correlation \(|\rho|\) between antenna \(u\) and \(v\) and emulated spatial correlation \(|\hat{\rho}|\) on two orthogonal axes (azimuth plane) for the 3 cases detailed in Table 1. Axis \(x\) is along the AoA of the target channel. The power weights are obtained by the Min-Sum algorithm.