MIMO OTA in a Small Anechoic Chamber

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Motivation

• NSF Enhancing Access to the Radio Spectrum (EARS)
  - Wireless system tests, measurements, and validation

• Next generation wireless standards use multiple antenna systems to increase connectivity and spectral efficiency.

• Certification of next generation devices is an expensive and time consuming process.
Multipath Channel

Multipath and Doppler fading in the channel
MIMO OTA Test Methods

- MIMO OTA test metrics are being standardized by 3GPP [1] and CTIA [5]

- Large anechoic chamber
  - DUT is surround by multiple antennas inside the chamber
  - Multi-cluster 2D measurements on a plane

- Small anechoic chamber
  - Single cluster 3-D measurements indicating DUT’s MIMO performance vs. orientation
  - 2-Stage method whereby antennas are measured in the chamber and then modeled using a traditional conducted fader

- Reverberation chamber
  - Uniform isotropic (3D) propagation is achieved via reflections from metal walls and mechanical stirrers
  - An external channel emulator is used to provide power delay profiles, Doppler and multipath fading
## Comparison of MIMO-OTA Methods

<table>
<thead>
<tr>
<th></th>
<th>Full sized anechoic</th>
<th>Reverberation chamber</th>
<th>Single cluster anechoic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Provides 2D performance information with 360° multi-cluster propagation</td>
<td>• Less expensive and smaller than full sized anechoic chamber</td>
<td>• Provides 3D performance information</td>
</tr>
<tr>
<td></td>
<td>• Requires a lot of space</td>
<td>• No information on where the nulls are in the antenna field</td>
<td>• Supports single cluster anechoic and 2-stage methods</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Takes little space</td>
</tr>
</tbody>
</table>
Conventional Chamber MIMO-OTA Testbed

- Base Station Emulator
- Channel Emulator
- RF Amplifier and Calibration Subsystem

Laplacian PAS

\[ \text{Laplacian spread} \]

-180° 0° 180°
Small Chamber MIMO-OTA Testbed

- Base Station Emulator
- Channel Emulator
- RF Amplifier and Calibration Subsystem

Single cluster UMa/UMi models
NSF Phase I: Accomplishments

• Goal is to analyze accuracy of the measurement as a function of angular spread of test antennas and number of antennas

• Developed synthesis algorithm to produce Laplacian PAS clusters in the test zone based on:
  - The wavelength used in the measurement
  - Test zone radius
  - Geometry of chamber and probe locations
  - Shape of probe field

• Algorithm calculates error of synthesized field vs. theory – Reflectivity [8]

PAS = power angular spread
Method – Plane Wave Synthesis

• Widely used *spherical wave theory* models 3D antenna radiation [8]

• *Plane wave synthesis* technique is based on spherical wave theory [8] and enables synthesis of Laplacian PAS cluster field

• Team created synthesis algorithm to generate Laplacian PAS
Field synthesis

• From spherical plane wave theory we can reduce the number of probe antennas

$$K = \frac{4\pi r}{\lambda} + 1$$

• With plane wave synthesis, a target field can be approximated

$$E_{\text{Target}}(r_0, \phi) \approx E_{\text{Synth}}(r_0, \phi) = \sum_{n=1}^{N} c_n E_n(r_0, \phi)$$

• Error or reflectivity between the desired and synthesis

$$e(r_0) = 20 \log_{10} \left( \max_{0^\circ \leq \phi < 360^\circ} \left( \frac{\left| E_{\text{Synth}}(r_0, \phi) - E_{\text{Target}}(r_0, \phi) \right|}{\max_{0 < r \leq r_0, 0^\circ \leq \phi < 360^\circ} \left| E_{\text{Target}}(r, \phi) \right|} \right) \right)$$
Synthesized electric field levels across the test zone agree with the theoretical field levels for the desired Laplacian PAS.

Note: Results are shown for a single instance in time
E-field at Max Test Zone Boundary

Synthesized electric field levels around the circumference of the test zone agrees with the theoretical field levels for the desired Laplacian PAS

Note: Results are shown for a single instance in time
E-field Error vs. Test Zone Radius

Reflectivity (error) is < 20dB up to 0.1m from the center of the test zone.

Reflectivity indicates the maximum E-field error at a given radius relative to the peak field over the entire test zone plane.

Note: Results are shown for a single instance in time.
Simulation Technique

• Simulate the generation of a target electromagnetic field in a test zone with different small anechoic chamber dimensions/parameters.

• The target EM field is a Laplacian-distributed Power Azimuthal Spectrum with a random phase a each angle $e^{j2\pi\beta}$ where $\beta=[0…1]$.

• Monte Carlo simulations to determine the reflectivity in the test zone with 95% and 0.25 dB error.
Simulation Configuration Diagram

<table>
<thead>
<tr>
<th>Number of antennas</th>
<th>Chamber height (m)</th>
<th>Chamber width (m)</th>
<th>PAS (° in degrees)</th>
<th>Frequency (GHz)</th>
<th>Test zone radius (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,4,5,6</td>
<td>1</td>
<td>0.95, 1.5 2</td>
<td>50,70,90</td>
<td>0.7, 2.4, 5.9</td>
<td>10,15,20</td>
</tr>
</tbody>
</table>
Simulated Reflectivity vs. # Probes, r0, width

CDF of Reflectivity for Two Configurations

- \( r_0 = 10 \text{cm}, N = 6, w = 2 \text{m} \)
- \( r_0 = 15 \text{cm}, N = 6, w = 2 \text{m} \)
- \( r_0 = 20 \text{cm}, N = 6, w = 2 \text{m} \)
- \( r_0 = 10 \text{cm}, N = 3, w = .95 \text{m} \)
- \( r_0 = 15 \text{cm}, N = 3, w = .95 \text{m} \)
- \( r_0 = 20 \text{cm}, N = 3, w = .95 \text{m} \)

Freq = 700 MHz
\( \sigma = 70^\circ \)
Summary of Simulation Results

• More probes required for bigger test zone radius to maintain the same accuracy (reflectivity)

• For a small laptop or pad sized test zone, 20cm test zone radius, it appears at least 6 probes are required to keep the error (reflectivity) below -15 dB

• Constraining the range of phase variation of the waveform will make this feasible

• Our effort has created a tool to help us optimize error vs. number of probes
Computation EM Simulations

- Field based simulations do not account for reflections and near-field effects
- Create a chamber model to analyze the performance of a realistic system
- Vacuum results are comparable
- Reflections and NF must be accounted for

<table>
<thead>
<tr>
<th>$r_0$ (m)</th>
<th>$N$</th>
<th>Lap. $\sigma$ (deg)</th>
<th>Freq</th>
<th>Width (m)</th>
<th>Matlab, vacuum</th>
<th>HIFSS, vacuum</th>
<th>HIFSS, chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mean ref. (dB)</td>
<td>std. dev. ref. (dB)</td>
<td>mean ref. (dB)</td>
</tr>
<tr>
<td>0.1</td>
<td>6</td>
<td>25</td>
<td>700 MHz</td>
<td>2.0</td>
<td>-36.7199</td>
<td>2.4177</td>
<td>-36.2777</td>
</tr>
<tr>
<td>0.1</td>
<td>6</td>
<td>35</td>
<td>700 MHz</td>
<td>2.0</td>
<td>-34.6884</td>
<td>3.5247</td>
<td>-34.2675</td>
</tr>
<tr>
<td>0.1</td>
<td>6</td>
<td>45</td>
<td>700 MHz</td>
<td>2.0</td>
<td>-30.7851</td>
<td>4.5645</td>
<td>-30.3239</td>
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<tr>
<td>0.1</td>
<td>3</td>
<td>25</td>
<td>2 GHz</td>
<td>0.95</td>
<td>-17.1502</td>
<td>3.6965</td>
<td>-17.3265</td>
</tr>
<tr>
<td>0.1</td>
<td>3</td>
<td>35</td>
<td>2 GHz</td>
<td>0.95</td>
<td>-14.3711</td>
<td>3.6514</td>
<td>-13.4716</td>
</tr>
<tr>
<td>0.1</td>
<td>3</td>
<td>45</td>
<td>2 GHz</td>
<td>0.95</td>
<td>-12.2670</td>
<td>3.5722</td>
<td>-11.3945</td>
</tr>
</tbody>
</table>
Verifying Laplacian Field

Fig. 3. The 2-D multi-probe system calibration setup of eight probes. The red crosses are the possible locations of the calibrating probe placed equidistantly with constant $\phi$ intervals ($\Delta \phi$) around the test zone of radius $r_0$.

Source: “Calibration Procedure for 2-D MIMO Over-The-Air Multi-Probe Test System”, by D. Parveg et al
Contributions

• Document for the CTIA MIMO-OTA Subgroup
• Submission to IEEE Transactions of Instrumentation and Measurements
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3) Charles Capps, “Near field or far field?”, EDN, Aug 16, 2001

4) CTIA, “Test Plan for Mobile Station Over the Air Performance - Method of Measurement for Radiated RF Power and Receiver Performance”, Revision 3.1, January 2011

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14) 3GPP TR 25.996, "3rd Generation Partnership Project; technical specification group radio access networks; Spatial channel model for MIMO simulations“


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17) “Calibration Procedure for 2-D MIMO Over-The-Air Multi-Probe Test System”, by D. Parveg et al