Holographic MIMO Communications

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GTII workshop

“Wireless Intelligence: From Reconfigurable Surfaces to Edge/Cloud Communications”
Promising wireless applications

- Holographic MIMO, Large intelligent surfaces (LIS), Reconfigurable intelligent surfaces (RIS), Extremely large aperture arrays (ELAA)
- All aiming at increasing the spectral efficiency (bit/s/Hz)
The Fraunhofer far-field assumption

- The shift towards these applications poses new challenges
- The far-field assumption $R > L^2 / \lambda$ may break down in some of these applications
- Three examples at 3GHz:

<table>
<thead>
<tr>
<th>Massive MIMO</th>
<th>HMIMO/LIS</th>
<th>ELAA</th>
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<tbody>
<tr>
<td>8x8 array, half-wavelength</td>
<td>L = 4 $\lambda$</td>
<td>L = 3 m</td>
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<tr>
<td></td>
<td>R &gt; 16 $\lambda = 1.6$ m</td>
<td>R &gt; 90 m</td>
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<tr>
<td></td>
<td>YES</td>
<td>NO</td>
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<td>NO</td>
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A closer look at wave propagation

- New applications push us towards the Fresnel near-field region
- Wavefronts are not locally planar
- Communication theorists typically rely on classical MIMO far-field channel models

$\kappa$, $V_S$, $s$, $L$, $r'$, plane waves, far-field, radiating near-field, reactive near-field, Fresnel region, Fraunhofer region $R > \frac{L^2}{\lambda}$
Models for Wave Propagation

• Numerical electromagnetic solvers not useful for communication theorists
• i.i.d. Rayleigh fading overestimates the available DoF (proportional to the antennas)
• Stochastic random field models typically have a physically meaningless correlation
• No physically-tenable channel model to work with

The only class of meaningful channel model is the Fourier plane-wave model!
Linear-system theoretic formulation

- We model wave propagation as a linear and space-variant system
- Stationary channels are low-pass bandlimited in the spatial-frequency domain
Fourier plane-wave series expansion

- The channel response can be decomposed in terms of plane-waves
- Valid in the Fresnel near-field region and for arbitrary scattering
- Orthonormal description of the channel with statistically-independent Gaussian coefficients

\[
h(r, s) \approx \sum_{(\ell_x, \ell_y) \in \mathcal{E}_r} \sum_{(m_x, m_y) \in \mathcal{E}_s} a_r(\ell_x, \ell_y, r) H_a(\ell_x, \ell_y, m_x, m_y) a_s(m_x, m_y, s)
\]
Variance of the Fourier coefficients

Isotropic propagation (360° angle spread)  Non-isotropic propagation (5° angle spread)
Channel eigenvalues

- Planar squared array of side length $\frac{L}{\lambda}=10$
- $\frac{\lambda}{4}$-spaced antenna elements
Practical implications

- Closed-form, mathematically-tractable SVD of the channel response
- Valid in both the near-field and far-field and with arbitrary scattering
- Available DoF do not scale with the number of antennas
  - 3D (volume) arrays offer no extra DoF over two planar arrays
- Angular domain unitarily equivalent to the spatial domain but less redundant
- FFT-complexity data processing algorithms and channel estimation
Wish to know more?


