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Stochastic Electromagnetic Near-Field Green's Functions for MIMO Communications: Fundamental Theory and Applications to 5G/6G Wireless

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In this paper, we propose to develop alternative methods to handle correlation analysis in large-and-complex environments characteristic of both the current 5G the forthcoming 6G Wireless, which is expected to involve increasing numbers of user equipment (UEs) per unit cell combined with massive MIMO antenna arrays in base stations (BSs) [1]. In such scenarios, mutual coupling, strong correlation, and near field (NF) effects are very important but very difficult to handle using standard full-wave EM solvers available today. The present paper is based on the synergistic approach to electromagnetics and communications outlined in [2] and involve using Green's functions to describe interactions and correlation phenomena [3, 4]. Although these previous researches focused on far-field correlation, the most dominant type of correlation studied since the original work in [5], recently an interest in near-field correlation has emerged, motivated by the fact that in most dense and complex massive MIMO channels NF effects are prominent [6]. This paper aims at expanding the special cases studied in [7] to include generic and very broad spectrum of stochastic environments.

We provide a comprehensive framework for the analysis and design of MIMO antenna systems with focus on correlation phenomena. The proposed theory develops a general derivation of the stochastic cross-correlation between two generic antennas located at the base station (BS) of a multi-user multiple-input-multiple-output (MU-MIMO) system. Both user equipment (UE) antennas and arbitrary scattering clusters are replaced by proper infinitesimal dipole model (IDM). We avoid working with random field theory by relegating all statistical considerations to positions, orientations, and excitations of the UE antennas and scattering clusters while treating the latter as (generally) complex random vectors. An exact electromagnetic derivation of the BS correlation coefficient is achieved using reciprocity theory. The final expression is explicitly written in terms of a new generalized *stochastic correlation Green's function* (CGF) valid for *both* far- and near-field interactions. The CGF provides a complete and accurate description of all correlation-type phenomena in generic MIMO systems and internally generates the statistics of the BS illumination field based on NF source. We study the physical and stochastic structure of this Green's function in depth and explicate a four-point system interaction mechanism explaining how various components in the environment and UEs antennas contribute to the total observable port-port correlation in the BS. Moreover, the *causal structure* of the stochastic CGF is disclosed, where it is shown that conditional probability distributions are at the core of how correlation phenomena occur electromagnetically and statistically within the proposed computational paradigm.

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