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Channel Hardening in Reconfigurable Metasurface-Assisted Wireless Propagation: A Random Matrix Theory Approach

Gabriele Gradoni* (1) and Sirio Belga Fedeli(2)
(1) University of Nottingham, Nottingham, NG72RD, UK; e-mail: gabriele.gradoni@nottingham.ac.uk
(2) King's College London, London WC2R 2LS, UK; e-mail: sirio.belga_fedeli@kcl.ac.uk

Future wireless network architectures aim to achieve unprecedented signal coverage and data-rates via dynamic modulation of the propagation medium. A practical way to achieve this stands on the reconfigurable intelligent surface (RIS) technology, which uses pixelated reflective meta-surfaces with individually tunable unit cells. Besides improving signal coverage and reducing not spots, the RIS can mitigate the effects of signal variability underpinned by multi-path propagation fading. Inherently, channel Hardening (CH) occurs in Multiple-Input Multiple-Output (MIMO) systems where the wireless signal is spatially averaged through a large antenna array, thus reducing electromagnetic (EM) wave field fluctuations. As a practical consequence, the receive array perceives a dramatic reduction of the multi-path fading. However, the randomness is still present in the EM waves impinging onto the array, but the impact of signal fluctuations on the communication link is perceived weaker at receiver. While CH was observed in real-life propagation channel, both supporting idealized and non-idealized multi-path fading statistics [1], an interesting research question has configured over the last year within the wireless communication community, which asks whether CH can be achieved in RIS-assisted SISO wireless propagation channels. Some effort has been devoted to address this question from both system level and EM perspectives. It has been found that for phase-only control, optimal phase profiles of the RIS implies CH due to the law of large numbers [2].

In this work, we show that electromagnetic models of the discrete RIS, based on impedance and scattering matrices, can be augmented to include idealized Rician fading occurring within each and every propagation paths involved in multi-RIS assisted wireless links. Using tools developed in Random Matrix Theory (RMT) we elucidate the role of direct components on CH. Using the characteristic function method, we optimize the RIS in presence of fading and develop CH bounds for an arbitrary SISO wireless link. Theoretical results are validated with numerical Monte Carlo simulations.

Results are of interest for reducing the computational complexity carried by channel state information algorithms in mobile wireless networks, and to develop accurate protection technologies in directed energy scenarios.

1. C. Qin, Y. Miao, Y. Gao, J. Chen, J. Zhang and A. A. Glazunov, "Simulation-based Investigation on Spatial Channel Hardening of Massive MIMO in Different Indoor Scenarios and with Different Array Topologies," 2020 XXXIIIrd General Assembly and Scientific Symposium of the International Union of Radio Science, 2020, pp. 1-4, doi: 10.23919/URSIGASS49373.2020.9232421.

2. E. Björnson and L. Sanguinetti, "Rayleigh Fading Modeling and Channel Hardening for Reconfigurable Intelligent Surfaces," in IEEE Wireless Communications Letters, vol. 10, no. 4, pp. 830-834, April 2021, doi: 10.1109/LWC.2020.3046107.