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Impedance-based Signal Propagation Modeling with Reconfigurable Metasurfaces

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The role of reconfigurable metasurfaces for wavefront shaping has been a topic of broad research interest in physics, and very recently, in wireless communications. In the latter field, a metasurface with discrete 1-bit tunable elements operating at 2.45GHz has been fabricated and deployed for energy focusing within a multipath propagation environment [1]. This has been accomplished by adjusting the reflection phase of a two-dimensional array of metallic patches connected to the ground plane through a diode. The metasurfaces' technology promises scalable, zero-touch and low-cost energy relays capable of significantly lowering the propagation losses of the wireless channel and extending its reach. Lately, idealized versions of reflective metasurfaces, termed as Reconfigurable Intelligent Surfaces (RISs), have been considered for assisting the wireless communication between base stations and user equipment, and it has been theoretically proven that they are capable of: *i*) improving the spatial richness of wireless channels, thus increasing the spatial degrees of freedom, enabling distributed and three-dimensional massive Multiple-Input Multiple-Output (MIMO) systems; ii) providing agile configuration while operating with improved energy efficiency [2]; and *iii*) forming the basis for a reliable and secure physical layer for beyond fifth Generation (5G) and 6G mobile networks. It has been advocated that signal propagation modelling in environments with reconfigurable metasurfaces is an open research topic necessitating physics-based principles [3]. Particularly, it is of paramount importance to model the path loss, coherence time and spectra of a point-to-point link empowered by a RIS, as well as to estimate the number of orthogonal channels that can be generated to realize RIS-assisted MIMO systems. In this work, we consider a triangular system comprising of one Transmitter (TX) and one Receiver (RX) both equipped with dipole antennas, and a metasurface formed of multiple linear dipoles operating in passive mode and being parallel to both the TX and RX dipoles. We focus on the modeling of ElectroMagnetic (EM) waves impinging on the metasurface taking into consideration the near-field effects among its dipole elements, which are significant in such compact structures of radiating elements, as well as the near-field proximity of the metasurface to the TX and RX antennas. We present a complete end-to-end EM model using the impedance formalism that is comprised of closed form expressions for the self- and mutual-impedance between pairs of dipoles. The derived model results is an information theoretic channel matrix developed from first principle as well as to explicit formulas for the pathloss in both the near- and far-field regimes, which embed tunable impedance loads and geometrical parameters of the RIS passive dipoles. The proposed signal propagation model is suitable for designing digital signal processing algorithms to fully exploit realistic RIS operation as reconfigurable reflectors. It also extends the recent results of [4] providing a transfer function among the antenna ports that is further used for constructing the information theoretic channel matrix [5]. We show the importance of mutual coupling in both near- and far-field wireless links for not-so-large RISs Results are relevant in modern wireless systems including backscattering and Radio-Frequency IDentification (RFID) technologies.

References

[1] N. Kaina, M. Dupré, G. Lerosey, *et al.*, "Shaping complex microwave fields in reverberating media with binary tunable metasurfaces," *Scientific Reports*, 4, 6693, 2015, doi:10.1038/srep06693.

[2] C. Huang, A. Zappone, G. C. Alexandropoulos, M. Debbah, and C. Yuen, "Reconfigurable intelligent surfaces for energy efficiency in wireless communication," *IEEE Transactions on Wireless Communications,* 18, 8, Aug. 2019, pp. 4157–4170, doi: 10.1109/TWC.2019.2922609.

[3] E. Basar, M. Di Renzo, J. de Rosny, *et al.*, "Wireless communications through reconfigurable intelligent surfaces," *IEEE Access,* 7, 2019, pp. 116753–116773, doi: 10.1109/ACCESS.2019.2935192

[4] J. Bucheli Garcia, A. Sibille, and M. Kamoun, "Reconfigurable intelligent surfaces: Bridging the gap between scattering and reflection," https://arxiv.org/abs/1912.05344.

[5] S. Phang, M. T. Ivrlac, G. Gradoni, S. C. Creagh, G. Tanner, and J. A. Nossek, "Near-field MIMO communication links," *IEEE Transactions on Circuits and Systems I: Regular Papers,* 65, 9, Sep. 2018, pp. 3027–3036, doi: 10.1109/TCSI.2018.2796305.