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Statistical Mechanics Tools for Large-Scale Reconfigurable Intelligent Surface Design

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Programmable meta-materials are artificial structures engineered to have desired properties to dynamically control and manipulate EM waves [1]. The reconfigurable intelligent surface (RIS) based on discrete meta-surfaces with tunable elements has been widely studied in the wireless communication [2] and antenna [3] communities. Researchers have devoted substantial efforts in understanding how to devise pattern optimisation methods that achieve a specific scattering profile accurately. A key question arises on how efficiently to select the phase configuration that produces a RIS scattered field matching the prescribed scattering profile. In other words, the enormous parameter space provided by the array of RIS meta-atoms needs to be explored quickly within their available degrees of freedom. This is of paramount importance where a solution to the optimisation problem is not available in closed-form and thus constitutes an substantial computational task. In presence of binary meta-atoms, random [4, 5] and combinatorial [6, 7] exploration has been proposed, both proving practical and effective in achieving specific target functions within complex electromagnetic environments. We propose to find the optimal phase configuration by a physics-based approach inspired from quantum physics. The radar cross section formalism is used to calculate the RIS scattered wave energy, which is found to configure as an Ising Hamiltonian: A common mathematical abstraction employed in statistical mechanics to describe the spin state of arrays of quantum particles. An analogy can be made between the binary meta-atom state and the spin degree of freedom in order to design the reflection phase mask of the RIS. Here, we dwell on this analogy to develop an Ising model for the meta-surface array with prescribed scattering profile. The global solution of the problem, i.e., the values of the local reflection phases across the RIS, is obtained by computing the ground state of the effective Ising Hamiltonian. In particular, we consider the case of an oblique plane wave impinging on the reconfigurable meta-surface with the goal to achieve diffuse scattering. The ground state of the Ising Hamiltonian is thus found as an optimal solutions to the problem of diffusive meta-surfaces, either via simulated or quantum annealing. Finally, we compare the resource requirements of simulated and quantum annealing, and discuss a generalisation of the problem to arbitrary scattered fields. It is shown that methods using quantum annealing to tailor electromagnetic fields constitute a promising way forward towards the development of computationally efficient tools for the design of very large meta-surfaces.

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