Heuristic Quantum Optimization for Engineering Reconfigurable Intelligent Surfaces in Smart Radio Environments

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Reconfigurable intelligent surfaces (RISs) are software-controlled large engineered surfaces with many low-cost passive reflecting elements, where the desired reflective wavefront may be achieved by tuning the local reflection phase and/or amplitude of individual elements. Recently, we have seen a growing interest in using RISs to dynamically manipulate the propagation environment. Going beyond 5G and entering 6G, it is envisioned that large-scale, distributed RIS devices will be deployed at the surface of interacting objects, e.g. walls, windows, and furniture, in the propagation channel. The overall goal is to transform the radio environment into a smart and reconfigurable space that provides enhanced coverage with high energy efficiency and supports ultra-fast and seamless connectivity.

To harness the potential of the RIS-enabled smart electromagnetic (EM) environment, one needs to rapidly find the optimal states of RIS with prescribed objective functions. While there are mathematical tools like generalized Snell's law for anomalous reflection, there are no semi-analytical solutions for specific EM functionalities, e.g., multi-beamforming, energy focusing, diffusive scattering, and wireless functionalities, such as spatial diversity, data throughput, and physical-layer security. Therefore, various RIS optimization methods have been proposed in the literature. Despite these advances, it is still considered a challenging computational optimization task due to the enormous number of RIS configurations, the complexity of EM scattering environments, and the processing time constraints for wireless networks.

The proposed work stands on the fusion of statistical mechanics models with quantum computing (QC) algorithms to overcome the high computational optimization complexity in the RIS-aided smart radio environment. The philosophy is to recast the RIS-aided wireless and/or EM problem into a physical formulation that can be tackled efficiently with emerging QC hardware. As an example, the Ising model is widely used in statistical mechanics to describe the spin state of quantum particle arrays. In [1], we expand on this analogy and develop an Ising model for the RISs with beamforming/nullforming applications. By designing the Ising Hamiltonian to mimic EM scattered power, the optimal RIS configuration is encoded in the ground state solution of the Ising spin system, which can be effectively found by heuristic quantum optimization algorithms.

In this contribution, we advance this area of research in three directions. First, we evaluate and benchmark the performance of quantum optimization algorithms against classical heuristic algorithms. Second, we go beyond the basic beamforming applications and demonstrate the feasibility of the proposed methodology for weighted beamshaping and diffusive scattering applications. The emphasis is placed on the development of Ising Hamiltonian models in practical scenarios of wireless communication and radar engineering. Third, we discuss the use of hybrid classical-quantum algorithms for large-scale Ising optimization problems. The research outcomes are expected to be important in the emerging fields of smart EM environments and new wireless infrastructures, including high-capacity networks with reduced emission levels, smart skins for EM wave signal processing, and directed energy countermeasures to high-power EM coupling.

References

[1] C. Ross, G. Gradoni, Q. J. Lim, and Z. Peng, "Engineering reflective metasurfaces with Ising hamiltonian and quantum annealing," *IEEE Transactions on Antennas and Propagation,* vol. 70, no. 4, pp. 2841-2854, 2022.