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Combinatorial Optimization of Reconfigurable Intelligence Surfaces at Wireless Endpoints using the Ising Spin Glass Model

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Recently, we have witnessed an extensive and growing interest for leveraging reconfigurable intelligent surfaces (RISs) for dynamic manipulation of the wireless propagation environment [1,2]. The RISs are software-controlled large, engineered surfaces with many low-cost passive reflecting elements, where the desired reflective wave-front may be achieved by tuning the local reflection phase and/or amplitude of individual elements. Going beyond 5G and entering 6G, it is envisaged that large-scale, distributed RIS devices may be deployed at the surface of interacting objects, e.g. wall, windows, furniture, in the propagation channel. The general goal is to turn the wireless environment into a smart and reconfigurable space, which provides enhanced coverage with high energy efficiency and supports ultra-fast and seamless connectivity.

To harness the full potential of RIS-enabled smart wireless environment, one needs to rapidly optimize the states of RIS with prescribed objective functions that incorporate specific functionalities, e.g., beamforming, localization/focusing, channel diversity. This constitutes a substantial computational task in both the physical and network layer of wireless communication. Furthermore, the common assumption adopted in the wireless community is that the RISs are nearly passive due to minimal hardware complexity and power requirements. Namely, the RIS may not have the capability to sense the wireless channel and estimate the direction of arrival/departure (DOA/DOD). Hence, the channel estimation cannot be implemented on the RIS side, but rather at wireless endpoints (transmitter or receiver) of the communication link. This makes the channel estimation and optimization tasks very challenging.

The aimed scientific contribution in this paper is a physics-oriented, mathematically tractable computational framework that enables the optimization of RIS configuration without the need for a detailed knowledge of the propagation channel. The new idea stands on expressing the energy of channel transfer function elegantly as an Ising spin glass model. Thereby, the optimal solution of the problem, i.e., the values of the local reflection phases across the RIS, is converted into computing the ground state of a biased effective Ising Hamiltonian [3]. The advantages of doing so are threefold: (1) we show that it serves as a unified mathematical model for describing the wave physics in the RIS-assisted wireless network, including the multipath propagation and the static path that goes between the transmitter and the receiver without involving the RIS; (2) the ground-state solution of resulting physical formulation can be tackled efficiently with emerging quantum computing hardware, taking advantage of the fact that the quantum adiabatic evolution efficiently performs energy minimization in the Ising model; (3) the coefficients of the Ising spin bias and spin-spin interactions may be learned onsite by a generic supervised learning model known as factorization machine, which enables the possibility of ultra-fast optimization adapting to dynamic wireless environments.

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