

Site-Specific Codebooks for Reconfigurable Intelligent Surfaces

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Multipath propagation is ubiquitous in wireless communications due to the interactions between propagating waves and environmental objects. This phenomenon is site-specific, as it is influenced by factors such as channel geometry, material properties, and source configurations. As a result, multipath fading can either amplify or attenuate signal strengths in different regions.

In our previous study (Y. Liu *et al.*, “An equivalence principle-based hybrid method for propagation modeling in radio environments with reconfigurable intelligent surfaces,” *IEEE Trans. Antennas Propag.*, 2024), we demonstrated that multipath effects significantly influence signal strength at receiver locations in reconfigurable intelligent surface (RIS)-enabled communication channels. By accounting for multipath effects in channel modeling, we gain a more comprehensive view of RIS channel behavior than by focusing solely on the direct link from the transmitter to the receiver via the RIS.

Typically, RIS codebooks are designed to meet specific performance metrics, such as main lobe directions and side lobe levels. However, in practical environments, these pre-designed configurations can lead to destructive interference in areas where strong signal coverage is desired, while inadvertently boosting signal strength in less critical regions, as a result of multipath fading.

In this work, we introduce a site-specific strategy for RIS codebook design. By leveraging ray-tracing to capture multipath effects, we tailor the codebooks to the unique characteristics of a given environment, thereby enhancing signal strengths at designated receiver points. We formulate the design as an optimization problem aimed at maximizing the received signal strengths (RSSs) contributed by all relevant rays, including direct rays and those that undergo multiple reflections, transmissions, and diffractions. A convolutional neural network (CNN) model (Y. Liu and C. D. Sarris, “A convolutional neural network based method for accurate computation of scattered fields from reconfigurable intelligent surfaces,” *IEEE Trans. Antennas Propag.*, 2025) is employed to accurately and efficiently compute scattered fields from an RIS for arbitrary configurations, fully considering the mutual coupling between unit cells. Based on this CNN model, we propose a method that directly maps RIS configurations to the resulting signal strengths, ensuring that the computational cost remains comparable to conventional methods that do not account for multipath effects.

We compare our codebook designs both with and without multipath considerations. The results show that our approach consistently outperforms the generic codebook design optimization followed in the RIS literature (e.g., T. Shan *et al.*, “Coding programmable metasurfaces based on deep learning techniques,” *IEEE J. Emerg. Sel. Top. Circuits Syst.*, 2020).