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Using a Digital Twin to Evaluate System Metrics of Reconfigurable Intelligent Surfaces

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In 5G and 6G research, Reconfigurable Intelligent Surfaces (RIS) are gaining attention to overcome the high channel fading and path loss at millimeter wave (mmWave) frequencies. RIS offer methods to connect users at mmWave enabling better connectivity in urban environments [1]. Optimal design of RIS should include the operational context, which complicates design due to the many interconnected design variables that must be considered spanning the metasurface hardware, control algorithms, and deployment location.

We present methods for RIS realization that include element-level design using electromagnetic fields solvers and integrated system-level design that considers performance of link level metrics. We use the metrics Bit Error Rate (BER) and Signal to Noise Ratio (SNR) to evaluate the performance of an RIS-enabled link and to optimize RIS design within a relevant operational context. We create and use a 'digital twin' model to capture the performance of the RIS in a deployment scenario enabling simulated tests of a system prior to deployment.

Full wave simulation directly solves Maxwells Equations with a high degree of accuracy but is computationally prohibitive for use in evaluating the performance of an RIS within a 5G or 6G deployment scenario. For this reason various simulation techniques are used in our 'digital twin'. In our example, RIS unit cells are analyzed using a full wave simulation due to its ability to analyze arbitrary geometries. We then use the forward scattering model based on [2] to efficiently model the full metasurface response. To evaluate system performance given a deployment scenario, we integrate our forward scattering model with an open-source geometric ray tracing simulator known as NVIDIA's Sionna [3]. This integration allows for 5G link-level simulation of a digitally twinned electromagnetic propagation environment, avoids computationally impractical full-wave simulation of the environment, and enables evaluation of unit cells by use of the system-level metrics BER and SNR.

In this work, we present a digital twin of a realistic multipath scenario on the campus of the University of Colorado Boulder, and we compare unit cell performance by means of system-level metrics. Our framework is general such that it enables system-level evaluation of various unit cell designs against targeted deployment scenarios. We present various unit cells which vary in polarization, bandwidth, and number of control bits and show how they impact the system level parameters presented above.

Citations

[1] C. Pan, et al., "Reconfigurable Intelligent Surfaces for 6G Systems: Principles, Applications, and Research Directions," IEEE Communications Magazine, vol. 59, no. 6, pp. 14-20, 2021.

[2] C. Scarborough, Spatially-Discrete Traveling-Wave Modulated Electromagnetic Structures, 2022.

[3] J. Hoydis, et al., "Sionna: An Open-Source Library for Next-Generation Physical Layer Research," arXiv preprint, 2022, https://arxiv.org/abs/2203.11854.