

Synergizing Reconfigurable Intelligent Surfaces and Optimization-driven ML Models for Advanced Hybrid Beamforming in Next-generation Wireless Power Transfer

Sakib Reza, and Ifana Mahbub

Department of Electrical and Computer Engineering, The University of Texas at Dallas,
Richardson, Texas, USA (sakib.reza@utdallas.edu, ifana.mahbub@utdallas.edu)

The increasing dependence on drones for critical applications such as surveillance, reconnaissance, and defense operations necessitate innovative power solutions to address the constraints of limited battery life. Wireless power transfer (WPT) presents a promising alternative by facilitating continuous in-flight charging for multiple drones, thereby ensuring uninterrupted mission readiness in defense scenarios where operational endurance is paramount. Nevertheless, the effective delivery of power to dynamic, moving targets remains a substantial technical challenge. A hybrid beamforming approach, combining phase gradient having the property of direction control and Bessel beams known as non-diffractive focusing beams, provides a more effective solution than single-beam techniques, offering precise control over power distribution, enhanced coverage, and adaptability to varying drone positions. While phase gradient beams provide dynamic control, Bessel beams ensure non-diffractive energy transfer over long distances, making the hybrid approach ideal for multi-drone scenarios often encountered in defense applications. To implement this, the method of moments (MoM) offers high-accuracy beamforming calculations, avoiding heuristic or ad-hoc approaches. However, MoM is computationally intensive, which can be a bottleneck in real-time applications. To address this, machine learning models can be integrated to deliver fast, accurate predictions, ensuring real-time adaptability while maintaining the precision of MoM-based simulations. This combination offers a robust and scalable solution for WPT in defense operations, where sustained drone functionality and operational flexibility are paramount.

A transmission metasurface is proposed to generate a non-diffractive focusing beam with direction control in the near-field regime. Designed for WPT at 5.8 GHz, it employs high-efficiency transmission cells capable of achieving precise phase distributions by adjusting cell sizes. The metasurface consists of a 10×10 array of unit cells, achieving a simulated focusing range of approximately 160 mm—significantly larger than typical point-focusing distances. Additionally, leveraging the generalized refraction law, the design achieves a beam deflection of around 25° from the normal, demonstrating excellent beam-steering flexibility. This metasurface is designed on a Rogers RT/Duroid 5880 ($\epsilon_r = 2.2$, $\tan\delta = 0.0009$, 3 mm thick) substrate. This design offers a practical solution for long-distance wireless power transfer with advantages such as extended focusing range, flexible beam control, and simplified fabrication.

The MoM can compute the surface impedance of a metasurface by solving boundary integral equations, enabling the synthesis of a hybrid beam with Bessel and phase gradient properties through tailored impedance profiles. This abstract presents a novel approach that reimagines the MoM solving process as a machine learning training task. Using an artificial neural network (ANN), the conventional MoM matrix is treated as a training dataset, transforming the machine learning training process into a standard linear algebra-based MoM solution. The final trained model provides the MoM solution, with multiple linear regression (MLR) employed for model training. The efficiency of the proposed machine learning based method of moments (ML-MoM) over conventional MoM is shown by extracting the surface impedances of the transmission metasurface required to realize the proposed hybrid beam.