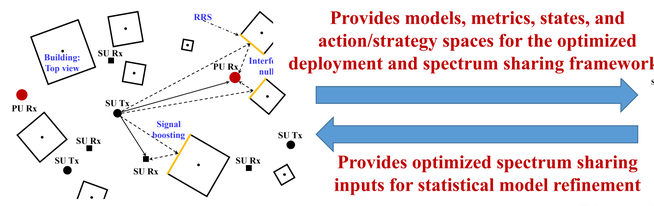
Enabling Seamless Coexistence between Passive and Active Networks using Reconfigurable Reflecting Surfaces

Harpreet S. Dhillon (VT), Walid Saad (VT)
Mohammadreza Imani (ASU), David Smith (Duke)
ECCS-2030215 (VT), ECCS-2030068 (Duke and ASU)
www.ris.ece.vt.edu

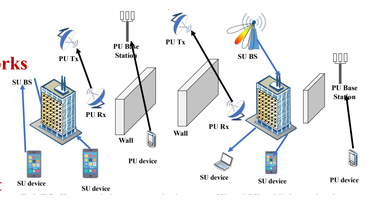
Project Overview

Project Goal: To develop a new cross-layer approach to enabling seamless spectrum co-existence between active and passive networks using Reconfigurable Reflecting Surfaces (RRSs).



Provides models, metrics, states, and action/strategy spaces for the optimized deployment and spectrum sharing frameworks

Provides optimized spectrum sharing inputs for statistical model refinement

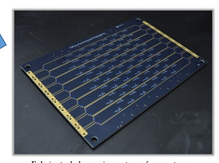


Thrust I: Statistical Modeling and Analysis of RRS-Enhanced Spectrum Co-existence

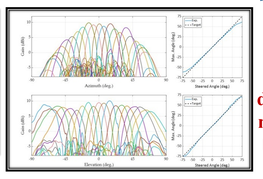
Provides novel experimental RRS and spectrum co-existence models for stochastic geometry analysis

Guides the experimental setup and practical modeling of RRSs and beamforming codebooks

Thrust III experimentation in 10-20 GHz. Specific emphasis on 10-68-10.7 GHz because of its relevance to many passive systems.



Fabricated dynamic metasurface antenna



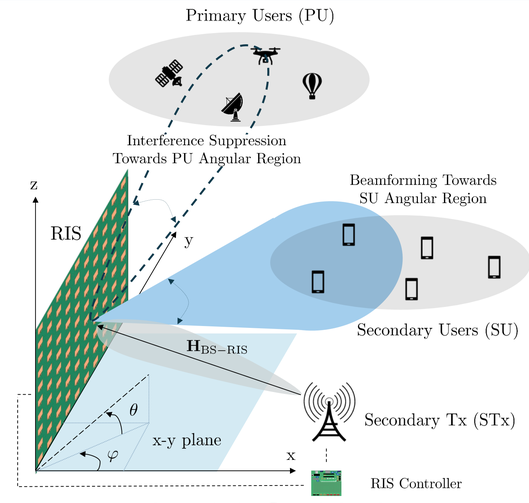
Thrust II: Optimized RRS Deployment and Spectrum Sharing for Seamless Co-existence

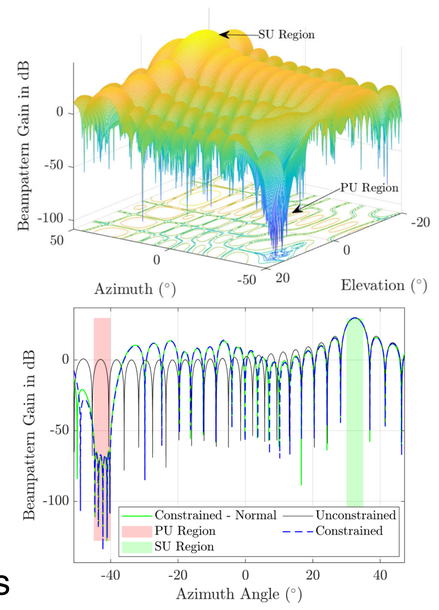
Optimized deployment and spectrum sharing for cross-layer evaluation

Guide and help refine the deployment and spectrum sharing mechanisms, including the facility location and multi-armed bandit frameworks and their optimization/equilibrium outcomes

Thrust III: Experimental Development and Practical Evaluation of RRS-Enhanced Spectrum Co-existence

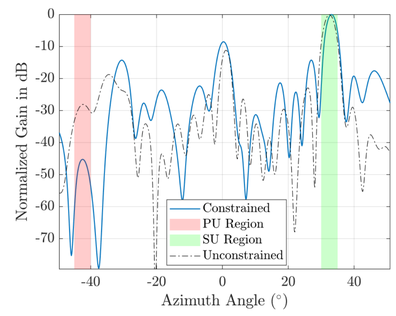
Thrust I: Modeling and Analysis of RRS-Enhanced Spectrum Co-existence





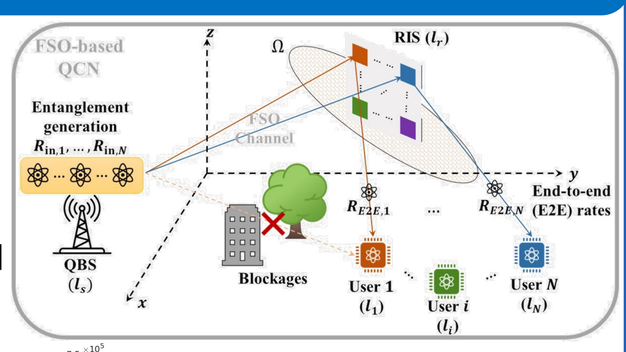
How to enable RRS-aided coexistence with a non-cooperative network? Our approach interprets non-cooperation as limited angular knowledge and verifies optimization efficacy through full-wave simulations.

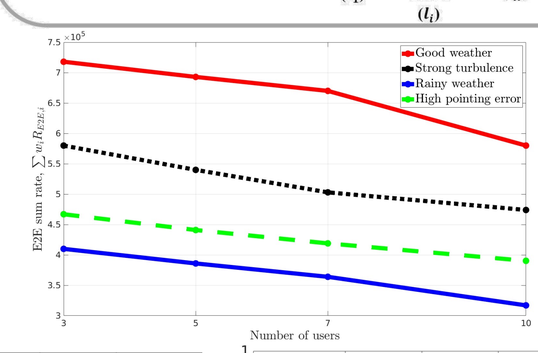
We have also developed a probabilistic optimization framework that can handle *any* discrete RRS optimization problem including spectrum co-existence.



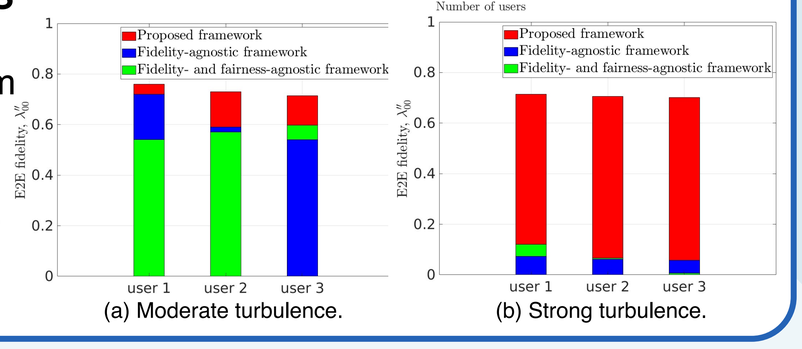
Thrust II: Optimized RRS Deployment and Spectrum Sharing for Seamless Co-Existence

How to integrate RRS with FSO quantum networks to enable entanglement distribution? We have jointly optimized RRS placement and entanglement rate allocation under environmental effects (weather, turbulence, and pointing error) and minimum rate and fidelity requirements.





How do classical and quantum networks with RRS differ? We have derived the quantum channel noise, and corresponding fidelity expressions.

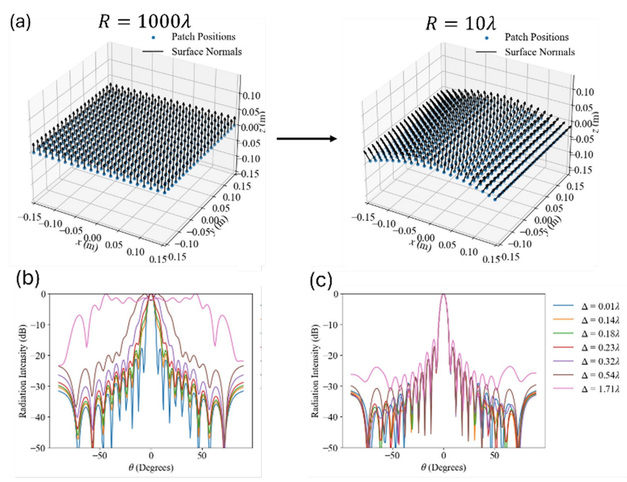


(a) Moderate turbulence.

(b) Strong turbulence.

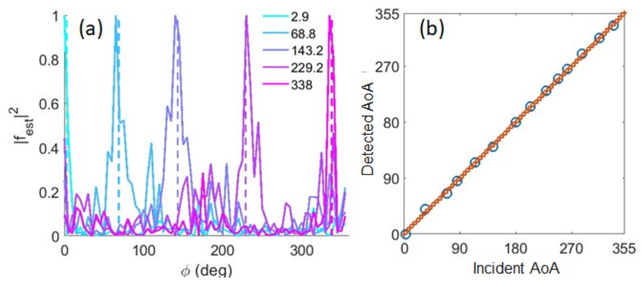
Thrust III: Experimental Development & Practical Evaluation of the Proposed Schemes

(a) Flat versus conformal RRS. (b) Beam profiles for RRSs, designed for a flat geometry, are curved. (c) Beam profiles for RRSs accounting for curvature.



How to accurately model RRSs for practical deployment? We have developed a quasi-analytical modeling of RRSs based on a coupled dipole model that can replace previous approximate formulas.

How to operate RRS-aided networks autonomously in practice? We have developed flat and conformal RRSs that can retrieve user's directions, even when using intensity of the incident signal.



Broader Impacts

The PIs have delivered multiple tutorials and short courses that included results from this project. They also engaged in several outreach activities. Representative activities are given below:

- Drs. Dhillon and Saad participated in panels at IEEE PIMRC 2023, where they discussed aspects of RRS, spectrum sharing, and other ideas from this project.
- Dr. Saad participated an event organized by the Center for the Enhancement of Engineering Diversity (CEED) within the Black Engineering Excellence at Virginia Tech (BEE VT) to discuss opportunities for wireless research.
- Dr. Imani's group presented their work at IEEE 2023 APS in a special session on "RIS/Metasurface Components and System Analysis for 5G-Advanced and 6G".
- The PIs participated in various other panels, workshops, and seminars germane to this project.

Next Steps

The PIs have already made significant progress across all three thrusts, including collaborative works on coexistence. Building on this progress, we plan to do the following in the remaining time:

- We are extending our probabilistic optimization framework to the case of physically consistent models of RRS allowing our analysis to predict the full-wave beampattern more closely, and to enable coexistence with a non-cooperative network.
- We are extending previous work on spectrum coexistence with RRSs by incorporating notions of resilience
- We are experimentally demonstrating RRSs that can detect users and reconfigure their radiation patterns.