Collaborative Research: SWIFT: Decentralized Intelligent Spectrum Sharing in UAV Networks (DISH-uNET) via Hardware-software Co-design

Mingyue Ji (PI, University of Florida), Rong-Rong Chen (Co-PI, University of Utah), Zhangyu Guan (Co-PI, University of Minnesota, Twin Cities) and Cunxi Yu(Co-PI, University of Maryland, College Park)

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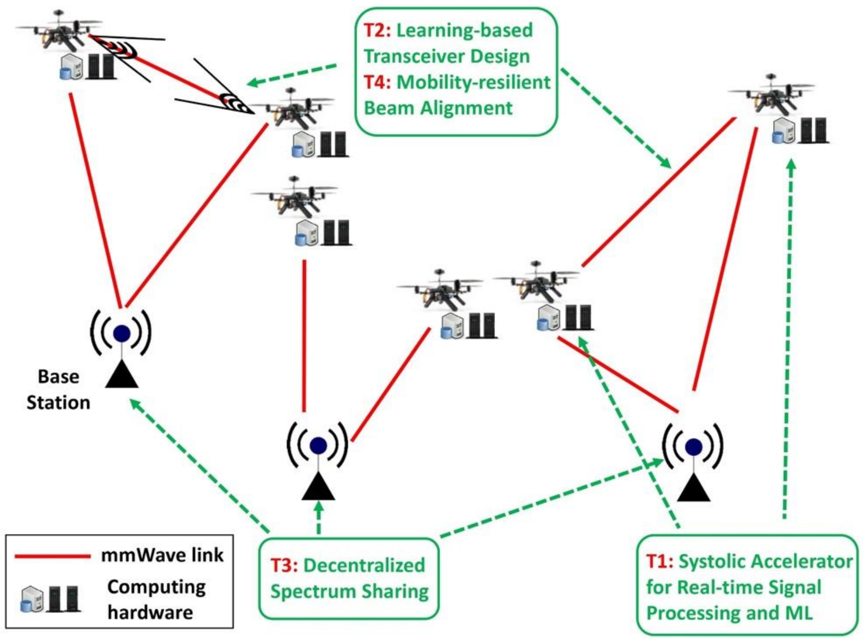
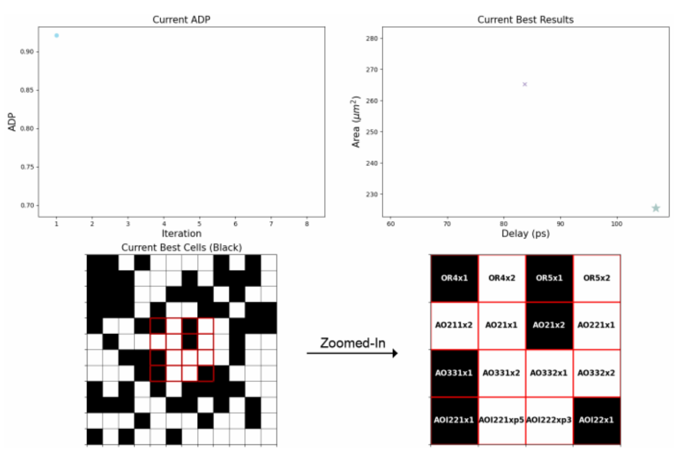
Project Description

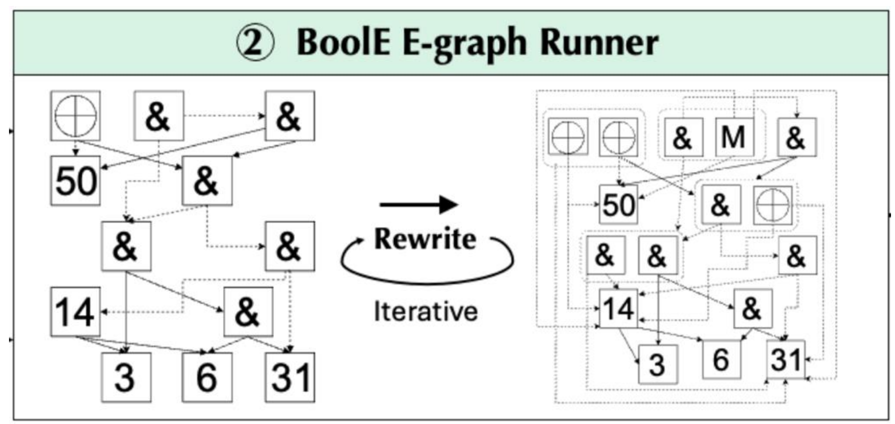
1. Develop novel approaches for decentralized intelligent spectrum sharing in mmWave UAV networks (DISH-uNET)
2. Achieve high efficiency and resilience based on hardware-software co-design
3. Design domain-specific energy-efficient systolic accelerators
4. Develop novel learning-based transceiver design for high mobility UAVs
5. Design new decentralized spectrum sharing multiple access control
6. Enable fast adaptation of mobility resilient mmWave beam learning for UAV networks and system prototype



Research Findings

- Thrust 1: Energy-efficient Systolic Accelerator for Simultaneous Real-time ML
  - **MapTune: RL-guided Design Flow Optimization for Low-power Chip Design**
    - First work to optimize optimize design flow from foundry libraries
    - Demonstrated in various technology nodes from 7nm, 45 nm, 90 nm, 130 nm
    - Technology transfers with two EDA vendors and one chip design vendor
  - **Equality Saturation for Hardware Synthesis**
    - Novel integration of formal methods with hardware synthesis to push frontiers of optimization runtime vs. quality of results
    - Versatile for mix workloads in targeted SWITF applications
    - Demonstrated quality-of-results over commercial AMD Xilinx FPGA compilers



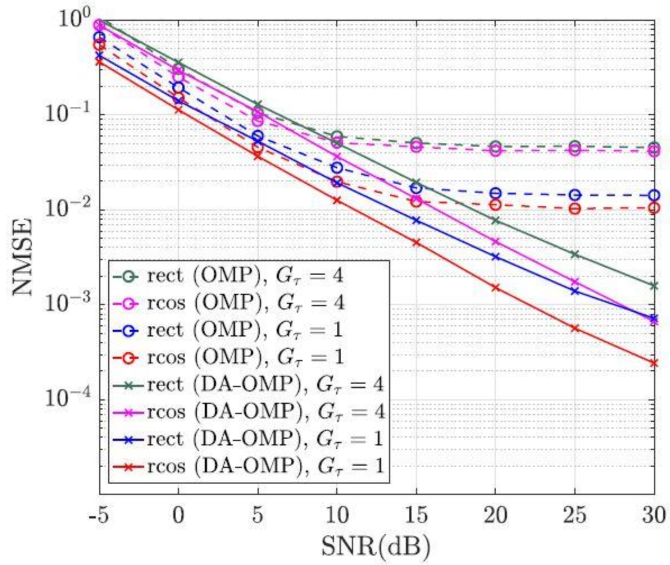


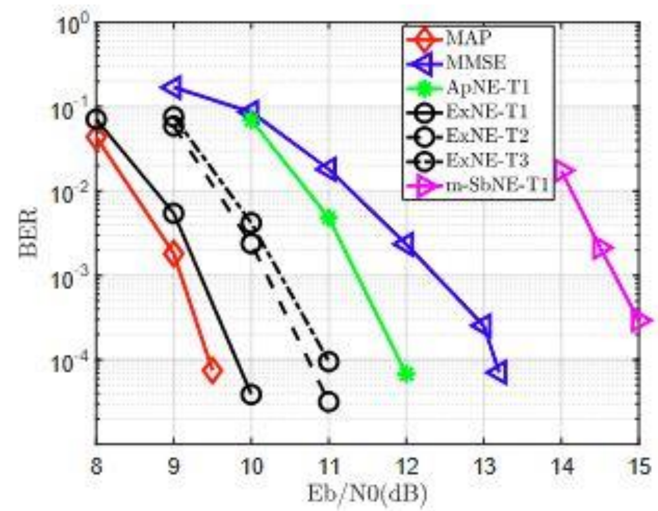
- Yin, J., Song, Z., Chen, C., Hu, Q., & Yu, C. (2025). BoolE: Exact Symbolic Reasoning via Boolean Equality Saturation. *DAC'25 [**Best Paper Finalists**].*
- Liu, M., Robinson, D., Li, Y., & Yu, C. (2024, October). MapTune: Advancing ASIC Technology Mapping via Reinforcement Learning Guided Library Tuning. ICCAD'24.

Research Findings

- Thrust 2: Transceiver Design for High Mobility UAV Communication
  - Proposed a delay-aware orthogonal matching pursuit (DA-OMP) algorithm and a windowed dictionary design to enhance delay–Doppler domain channel estimation by mitigating fractional Doppler effects.

  - Developed an extrinsic neural network equalizer (ExNE) and its meta-learning extension (Meta-ExNE) for turbo equalization over stationary and time-varying ISI channels, achieving superior performance over MMSE and APP-based neural network equalizers.

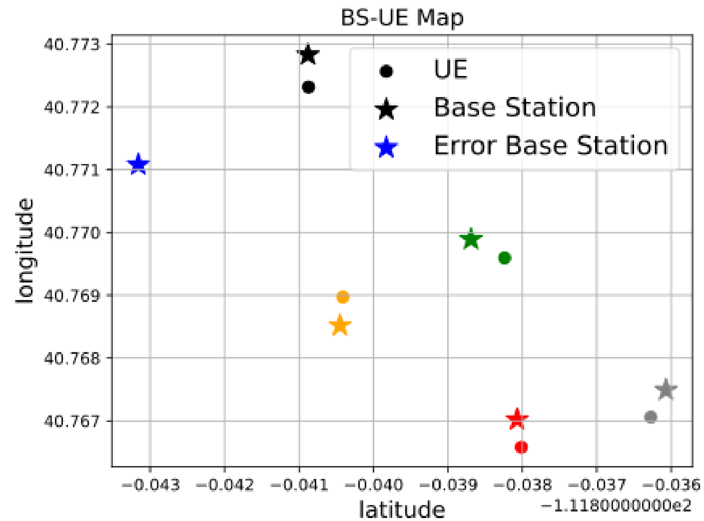




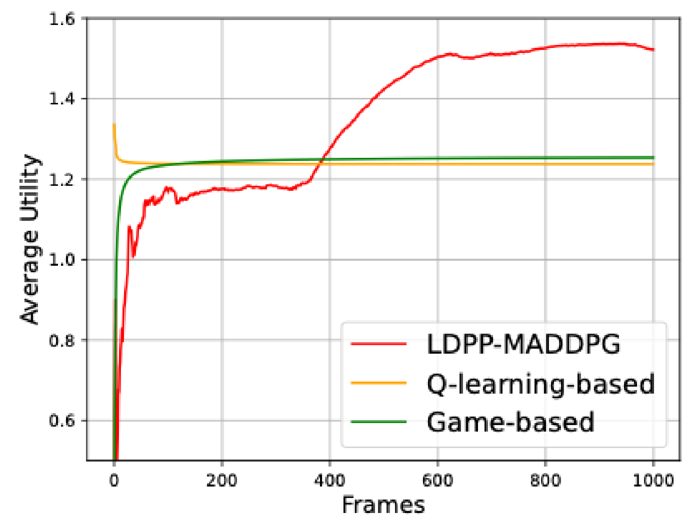
- Publications:
  - ``Windowed Dictionary Design for Delay-Aware OMP Channel Estimation under Fractional Doppler'', H. Wang, X. Huang, R.-R. Chen and Arman Farhang, Proceedings of IEEE International Conference on Communications, ICC'2025.
  - ``Extrinsic Neural Network Equalizer for Inter-Symbol-Interference Channels'', X. Huang, J. Cho, K. Hashemizadeh, and R.-R. Chen, submitted to IEEE Transactions on Communications, 2025.

Research Findings

- Thrust 3 : Bridging Lyapunov Optimization Framework, Game Theory, and Reinforcement Learning in Decentralized Spectrum Sharing
  - Propose a distributed continuous power allocation scheme based on a modified version of MADDPG that is tailored for the distributed multiple-agent setting.
  - The proposed scheme employs a centralized-training-distributed-execution framework
  - Effectively integrate the MADDPG into the Lyapunov optimization framework to achieve performance guarantees.
  - Experiments on POWDER.



POWDER Layout



- Publications:
  - H. Zhang, X. Huang, Z. Guan, R.-R. Chen, A. Farhang and M, Ji, "***Deep Reinforcement Learning for Maximizing Downlink Spectral Efficiency in Non-Stationary RIS-Aided Multiuser-MISO Systems,***" in 2025 EW Conferences.
  - X. Yao, A. Bhuyan, X. Zhang and M. Ji, "*A Novel LDPP-MADDPG Approach for Distributed Power Allocation in mmWave Cellular Networks,*" in 2025 MILCOM conference (workshop).

Research Findings

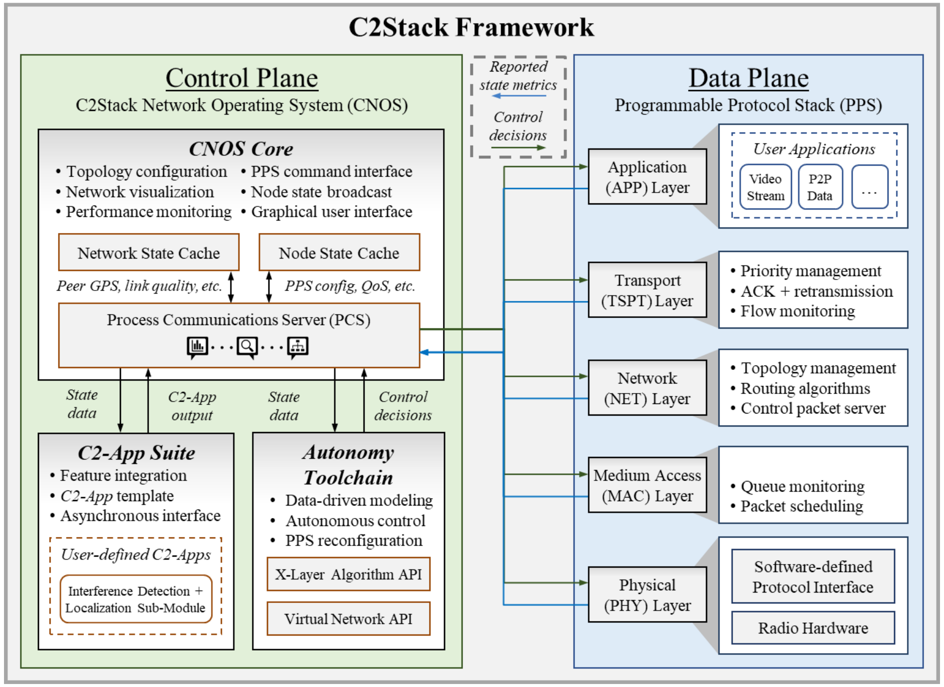
- Thrust 4: Mobility-Resilient mmWave Beam Learning and System Prototype

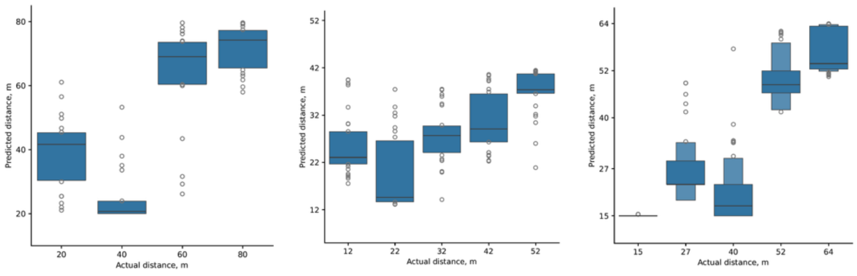
C2Stack: A configurable, extensible protocol stack for Communications and Control in UAV Networks

Full-scale prototype of intelligent UAV swarm network protocol
- Joint autonomous network self-configuration and swarm control
- On-board network simulator interface for DT-enabled research

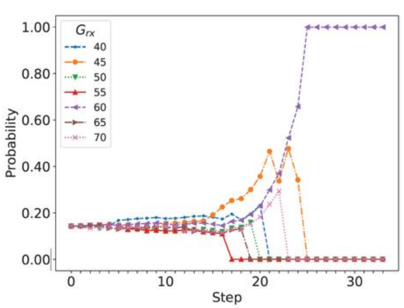
Data Plane – Programmable Protocol Stack (PPS)
- Open-source framework with independent, configurable layers
  - Very few external dependencies, many of which are open-source
- Resilient PHY-layer design
  - DSSS waveform with software-defined control interface

Control Plane – C2Stack Network Operating System (CNOS)
- Global control interface for consolidated control over all layers
- Synchronous monitoring and aggregation of network metrics
- Layer-specific optimization in parallel with network operation

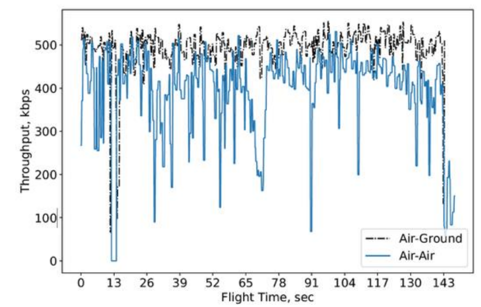




Results of data-driven RF interference distance estimation, based on network traces without dedicated RF sensing capabilities.



Selection of optimal PHY-layer parameters via data-driven self-configuration



Comparison of network throughput in air-ground (black) and air-air (blue) link configurations

- Publications: under submission

Thank you