Collaborative Research: SWIFT: Intelligent Dynamic Spectrum Access (IDEA): An Efficient Learning Approach to Enhancing Spectrum Utilization and Coexistence

Project Information

Project IDs:

- ECCS-2128594 (VT) --- leading institution
- ECCS-2128596 (GMU) --- collaborative institution

Personnel:

- PI: Lingjia Liu, ECE at Virginia Tech
- Co-PI: Yang (Cindy) Yi, ECE at Virginia Tech
- PI: Zhi (Gerry) Tian, ECE at George Mason University
- KP: Yue Wang, CS at Georgia State University

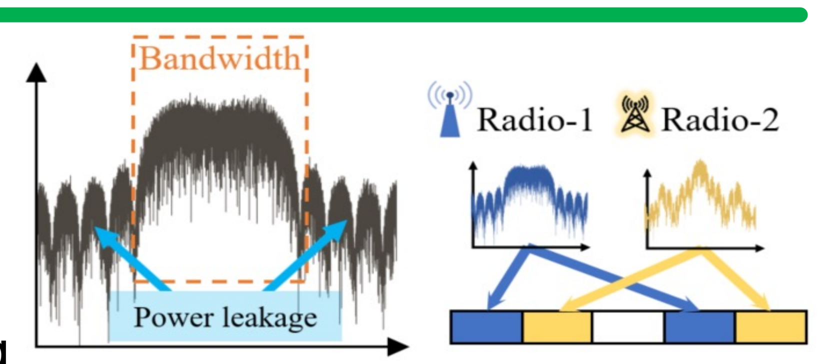
Project Objectives:

Develop learning-based technologies for intelligent wireless networks:
- Wideband spectrum sensing through efficient ML techniques;
- Collaborative learning for spectrum monitoring and cartography;
- Reinforcement learning based optimization for IRIS-system design.

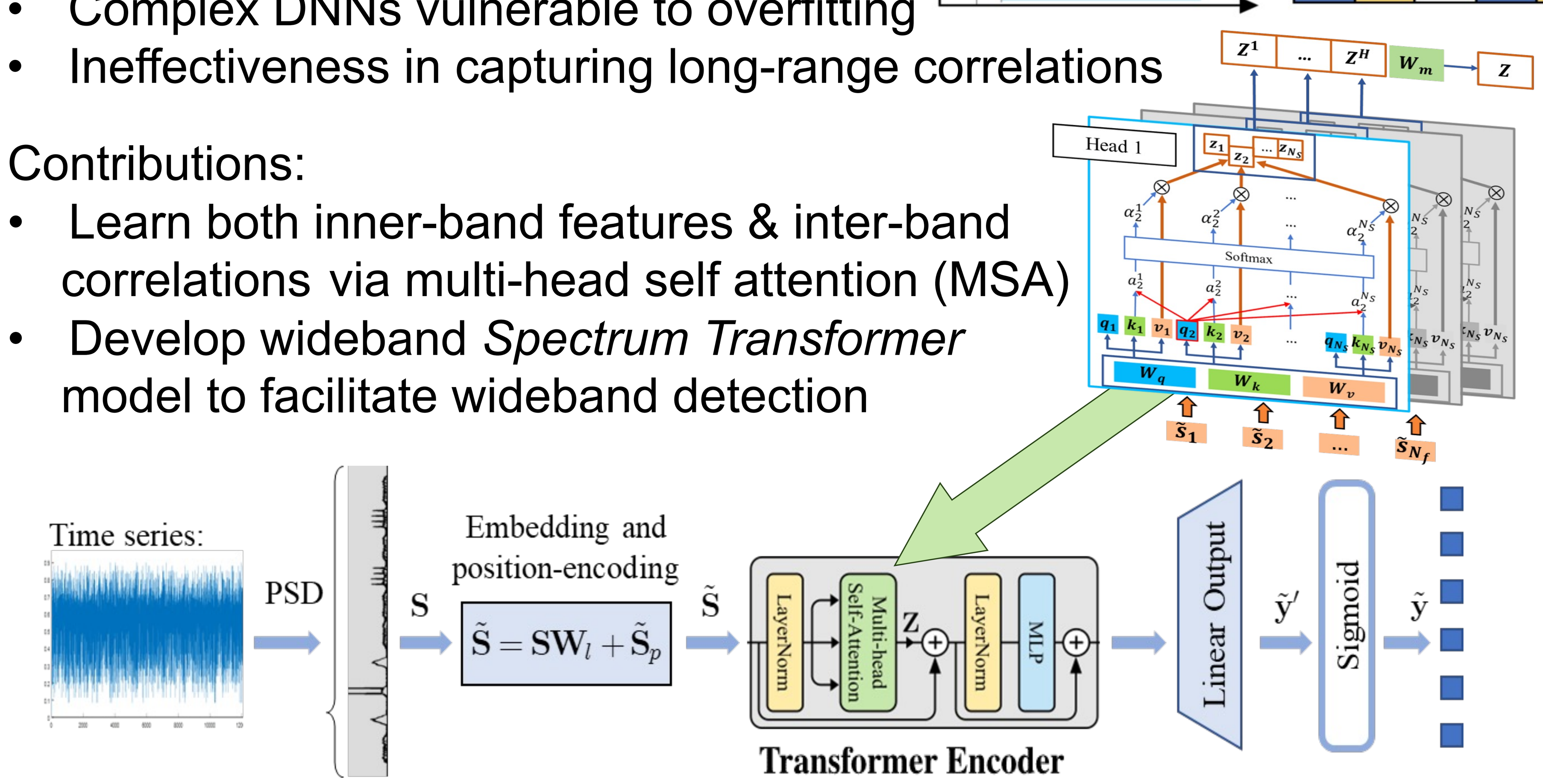
Research Activities

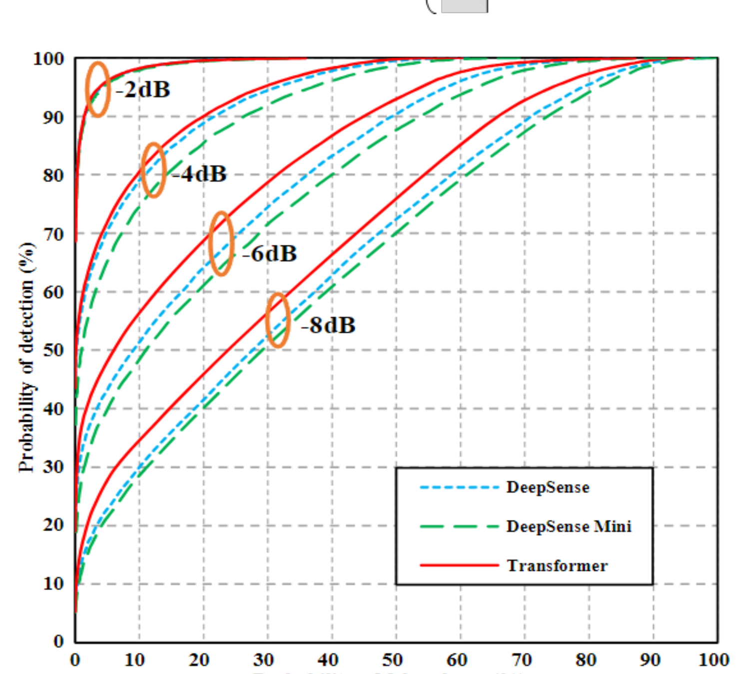
Spectrum Transformer

Challenges:
- Wideband data dimensionality boosts computation complexity
- Complex DNNs vulnerable to overfitting
- Ineffectiveness in capturing long-range correlations



Contributions:
- Learn both inner-band features & inter-band correlations via multi-head self attention (MSA)
- Develop wideband *Spectrum Transformer* model to facilitate wideband detection

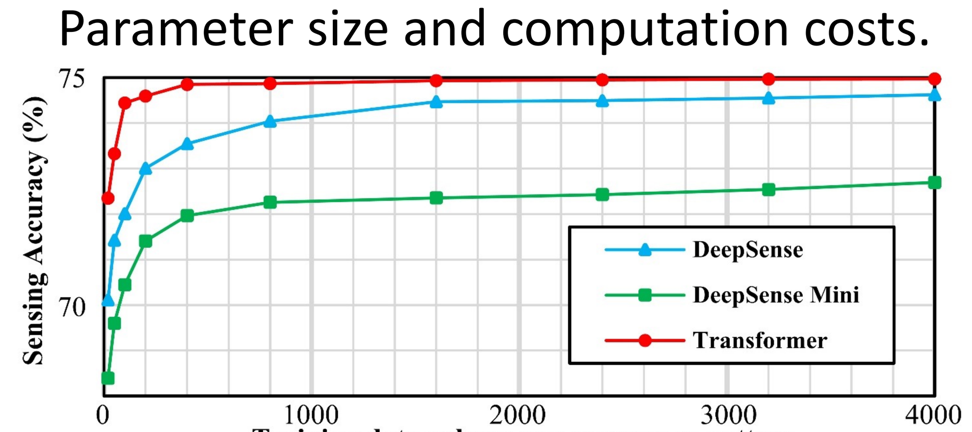




ROC of different methods

Complexity	Spectrum Transformer	DeepSense	DeepSense Mini
Parameter	6362	60346	6572
MACs	49312	3379200	64000

Parameter size and computation costs.



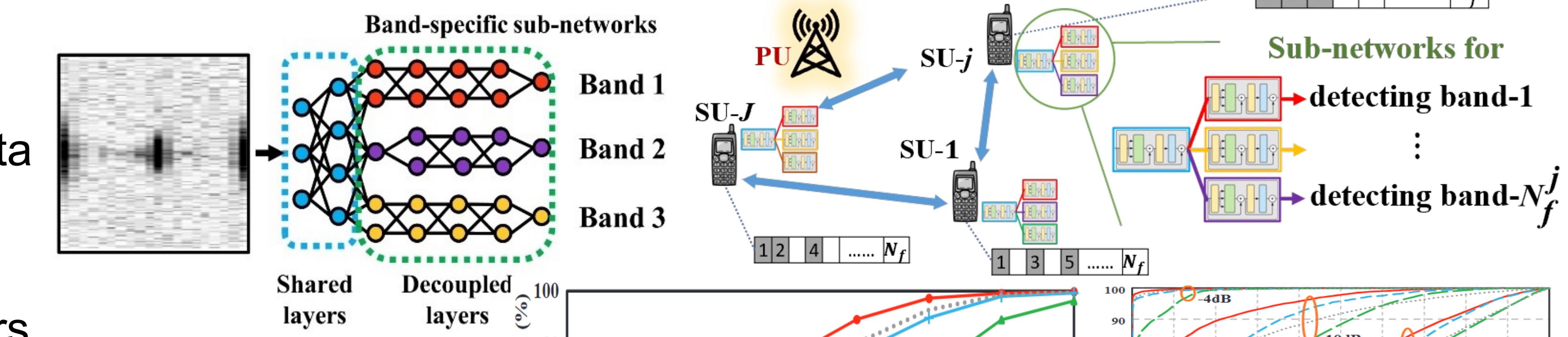
Accuracy under various data volumes

[1] W Zhang, Y Wang, X Chen, Z Cai, Z Tian, "Spectrum Transformer: An Attention-based Wideband Spectrum Detector" IEEE TWC, 2024.

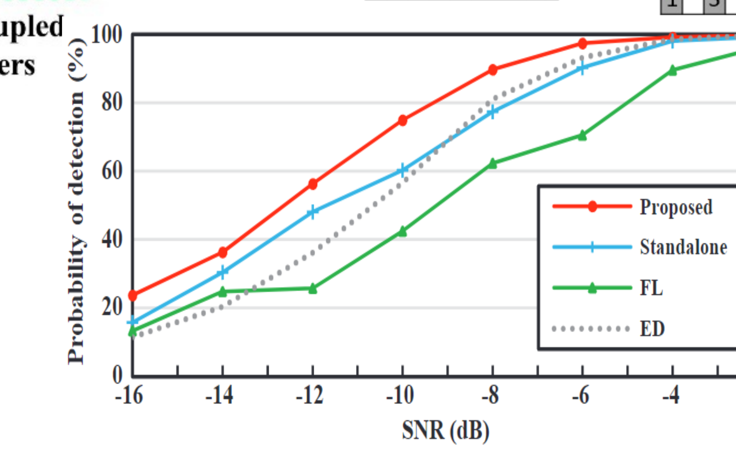
Collaborative Learning for wideband spectrum sensing

Challenges:
- Wideband sensing w/ partial observations
- Heterogeneous tasks and non-IID local data

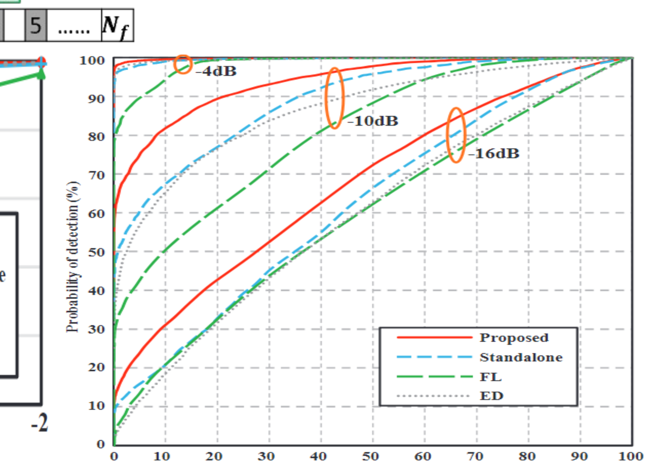
Contributions:
- Band-specific sub-network decoupling
- Collaborative learning with partial observers.



[2] W Zhang, Y Wang, X Chen, L Liu, Z Tian, "Collaborative Learning Based Spectrum Sensing Under Partial Observations" IEEE TCCN, 2024.



PD of different methods

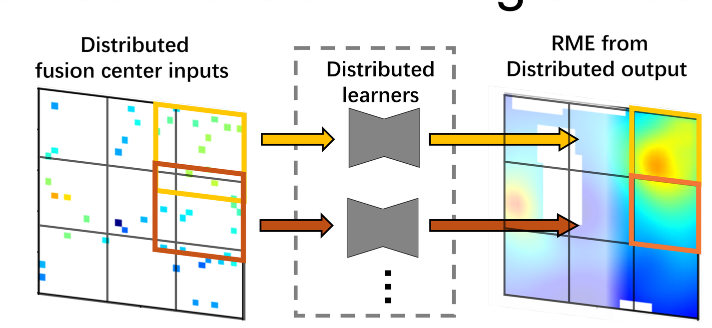


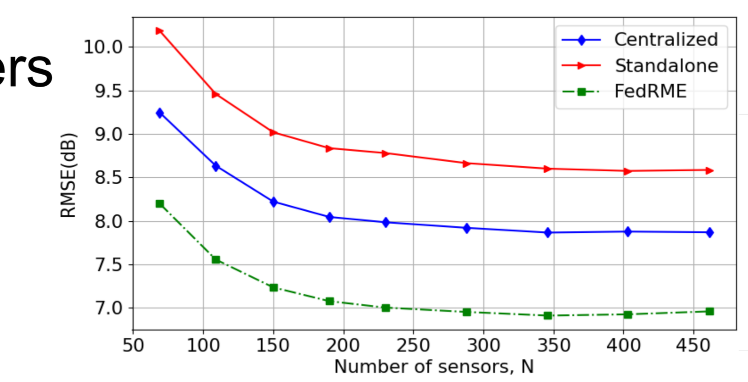
ROC of different methods

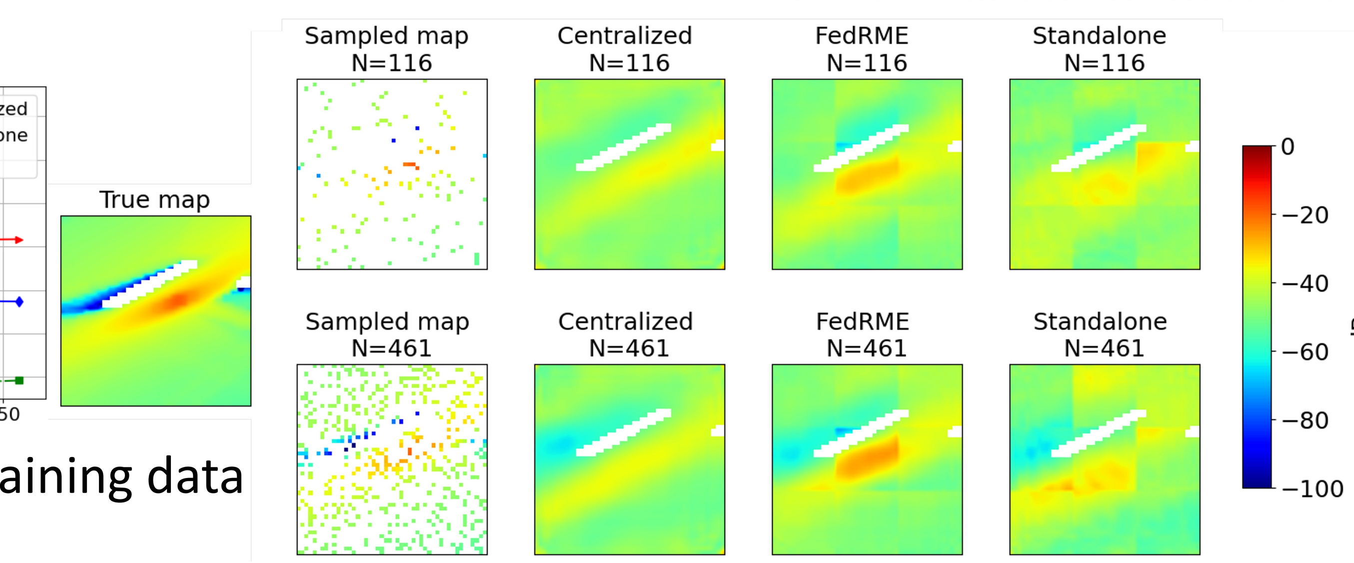
Federated Radio Map Estimation (FedRME)

Challenges:
- For large scale, high dimensionality causes model complexity
- Sparse observation leads to data scarcity and overfitting

Contributions:
- Partition area among distributed learners
- Each estimate small region radio map







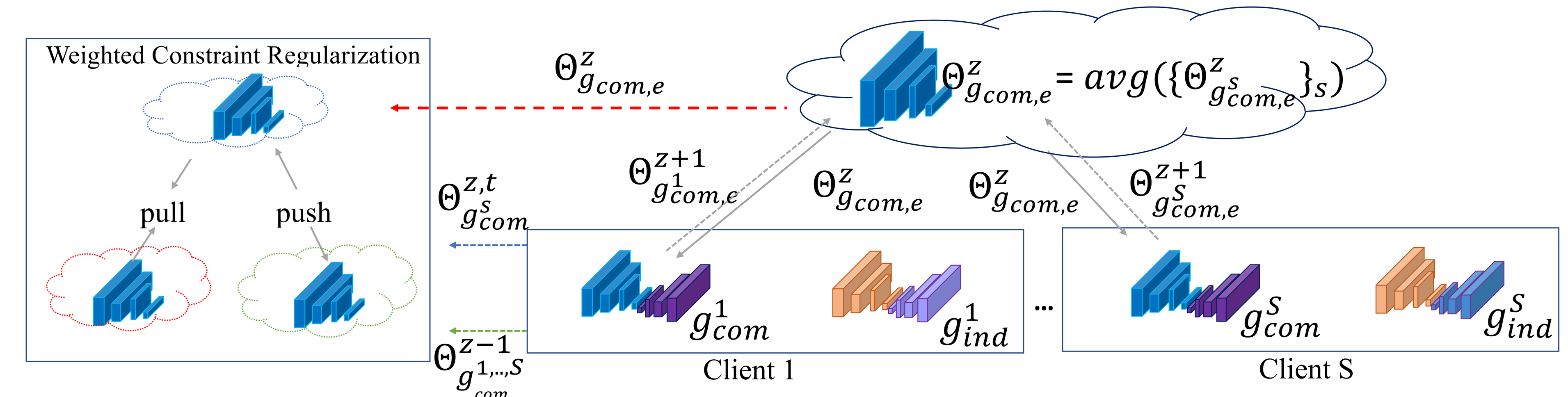
Collaborative learning w/ limited training data

[3] W Zhang, Y Wang, L Liu, Z Tian, "FedRME: Federated Learning for Enhanced Distributed Radiomap Estimation" IEEE VTC 2024 Fall.

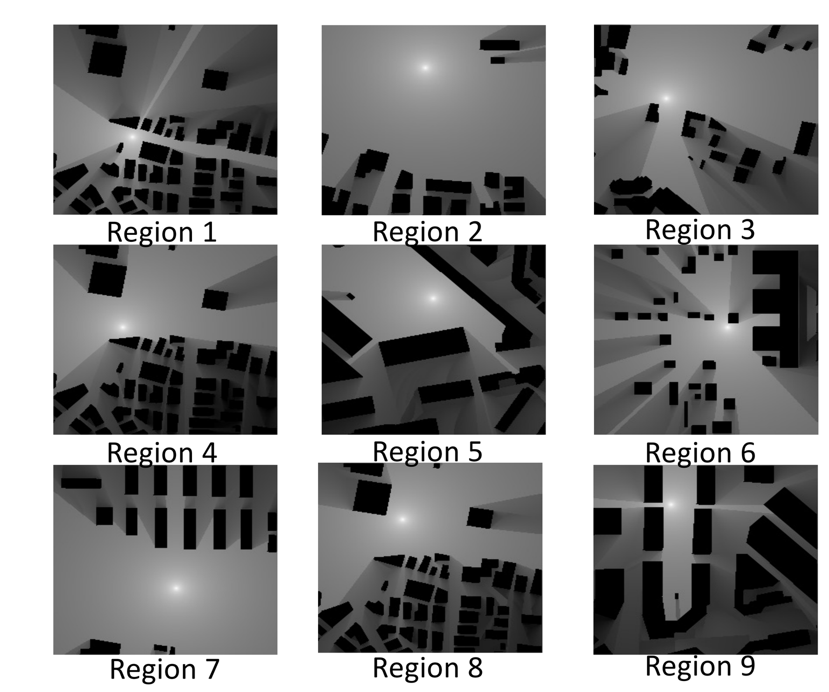
Physics-Enhanced FedRME

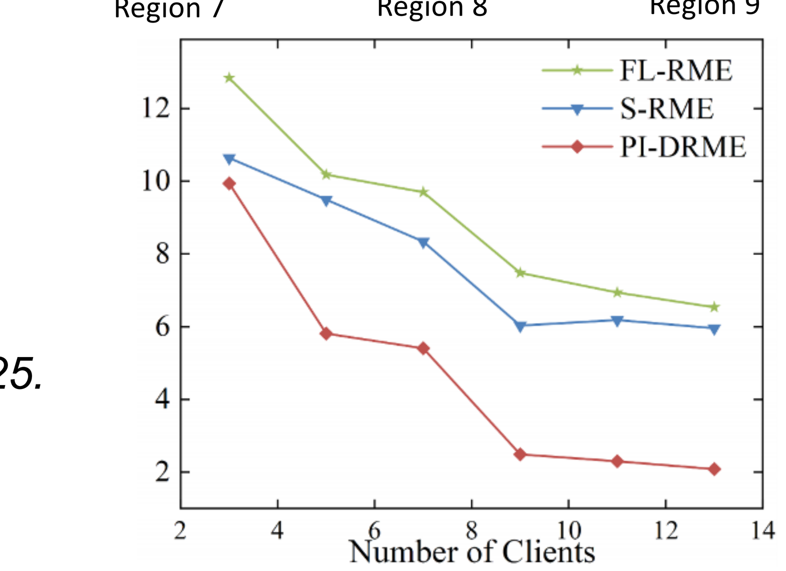
Challenges:
- Heterogeneous local environments, data and tasks

Contributions:
- PE-FedRME by using log-distance path loss model to guide a shared autoencoder
- Each client trains a local autoencoder for client-specific propagation in shadowing



[4] D Yang, Y Wang, S Zhang, Y Li, Z Cai, "Physics-Inspired Distributed Radio Map Estimation" IEEE ICC 2025.

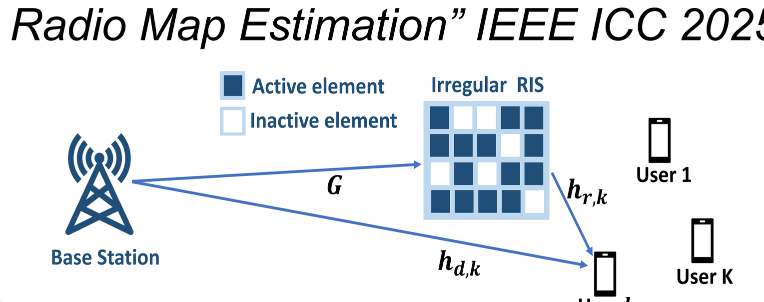




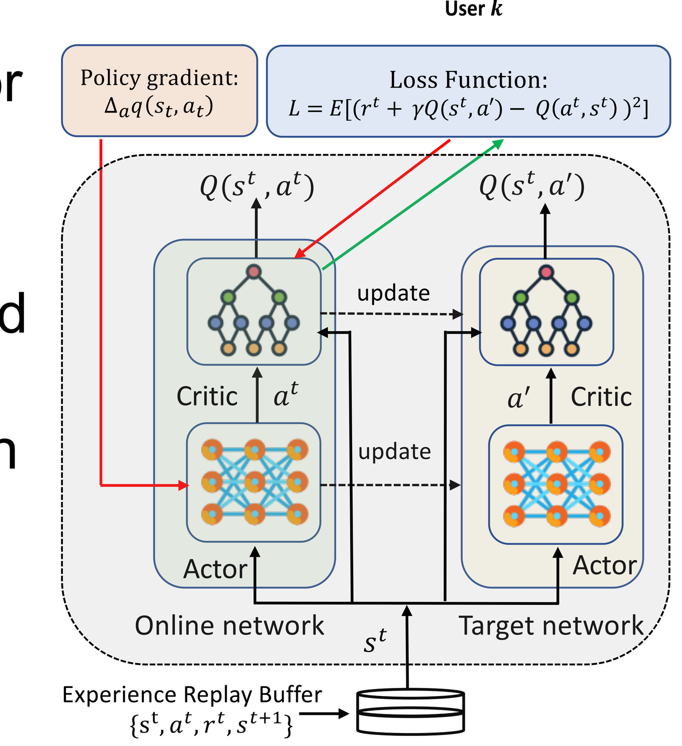
Collaborative learning among clients

RL-based irregular-RIS Optimization

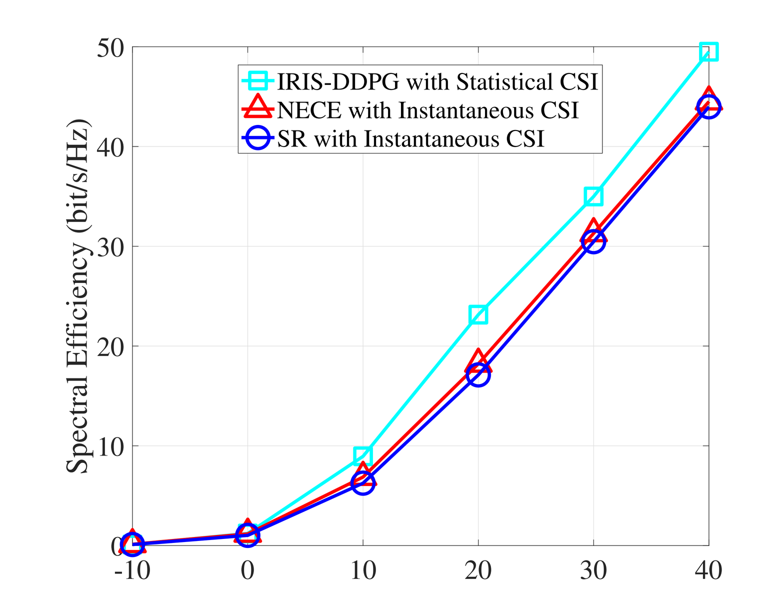
Challenges:
- Distributing power across increasing RIS antenna array
- CSI acquisition complexity and vulnerability to sensing error
- Mixed-integer programming with hybrid variables



Contributions:
- IRIS-DDPG for both discrete antenna element selection and continuous phase shifts and beamforming
- Considering the impact of channel estimation errors, design DRL reward function of SE/EE based on channel statistics



[5] E Frimpong, Y Wang, Z Tian, "Reinforcement Learning-based Optimization for Irregular Reconfigurable Intelligent" IEEE TCCN 2025.



Performance under Ch. Est. errors