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 (George Mason) ---- collaborative institution

Key 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

Project Summary:

The goal is to introduce IDEA that offers a holistic approach to develop enabling technologies for intelligent DSS networks:

- Analog/mixed-signal neuromorphic computing hardware.
- Improving spectrum utilization/coexistence through DRL learning.
- Wideband spectrum sensing through efficient ML techniques.

Research Progress

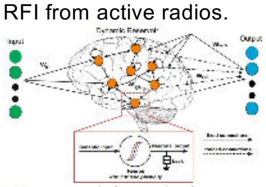
- Thrust 1 focuses on multiplexing neural encoding and efficient training for resource constrained secondary radios to enable on-board intelligence;
- Thrust 2 focuses on a reservoir computing structure to facilitate deep reinforcement learning for efficient spectrum utilization & coexistence
- Thrust 3 focuses on Spectrum Transformer & Collaborative Learning for wideband spectrum monitoring to detect RFI from active radios.

Mixed-signal neuromorphic computing

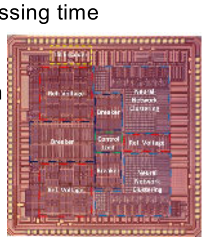
We designed and fabricated a multiplexing encoder and reservoir computing, which is a neurologically inspired concept for processing time dependent data.

—Fast processing speed

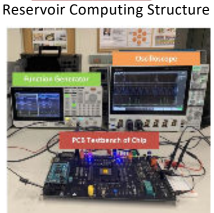
—Low power consumption



Reservoir Computing Structure



AI Chip with multiplexing encoder and reservoir computing



Testbench for measurement

Deep reinforcement learning for spectrum access & coexistence

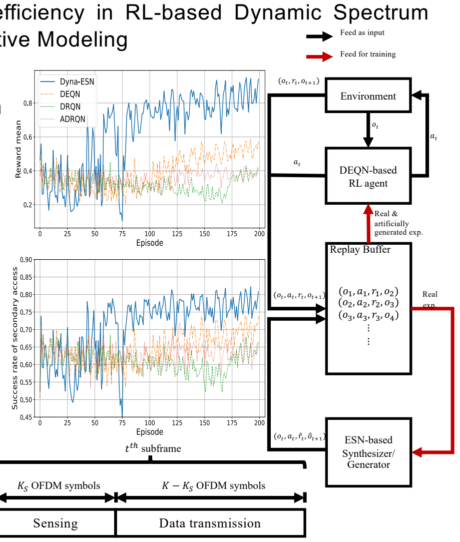
We improved sample efficiency in RL-based Dynamic Spectrum Access through Generative Modeling

Challenges:

- Opportunistic spectrum access in partially observable and highly dynamic wireless environments.

Contributions:

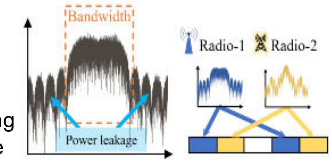
- Novel DRL algorithm w/ generative ESN-based model of environment to enhance convergence speed
- Evaluation metric for discarding inaccurate synthetic samples



Spectrum Transformer

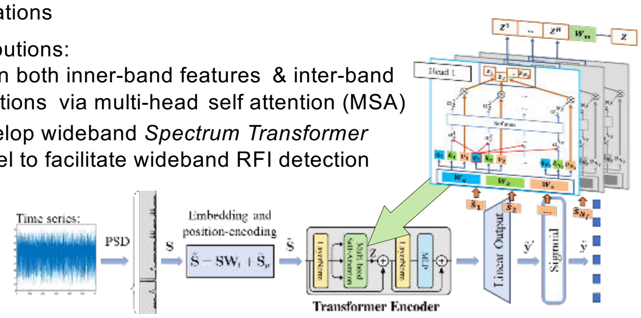
Challenges:

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



Contributions:

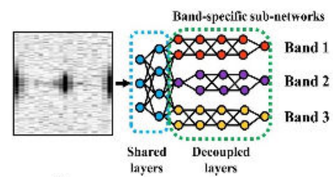
- Learn both inner-band features & inter-band correlations via multi-head self attention (MSA)
- Develop wideband *Spectrum Transformer* model to facilitate wideband RFI detection



Collaborative Learning for wideband spectrum monitoring

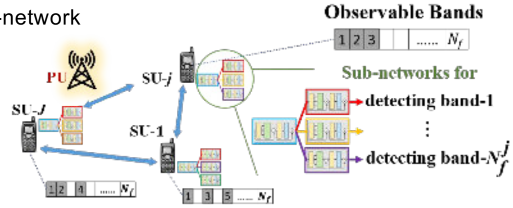
Challenges:

Wideband RFI monitoring w/ partial observation: heterogeneous tasks and Non-IID local data



Contributions:

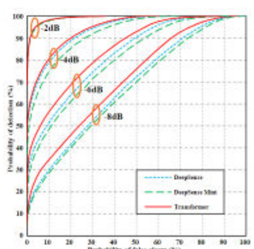
- Multi-band deep NN model and band-specific sub-network decoupling
- Collaborative learning with partial observers.



Numerical Results

Spectrum Transformer:

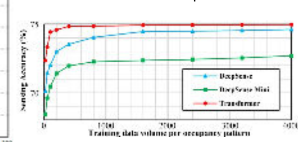
- Power leakage and band aggregation.
- 10 bands: 4 PUs using aggregated bands and 3 PUs using single band.
- Training data: 6400 wideband PSD.
- CNN (large & small) vs Transformer



ROC of different methods

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

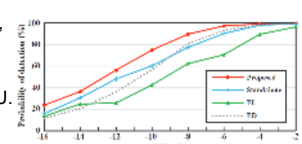
Parameter size and computation costs.



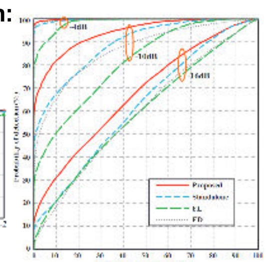
Robustness to overfitting: accuracy under various data volumes (SNR=-4dB)

Collaborative learning for partial observation:

- 20 bands,10 PUs and 10 SUs: each PU uses 1~3 bands while each SU can observe 4~8 bands.
- Our proposed method, FL, standalone, and energy detection.
- 10240 training data/SU.
- 35m x 60m area



PD of different methods



ROC of different methods

Future Directions

- We will develop distributed spectrum cartography and transmitter localization in multi-system spectrum sharing and coexistence.
- We will focus on efficient techniques for on-board intelligence at ultra-low power for resource-constrained secondary active radios

[1] Weishan Zhang, Yue Wang, Xiang Chen, Zhipeng Cai, and Zhi Tian, "Spectrum Transformer: An Attention-based Wideband Spectrum Detector." IEEE TWC, 2024 (Early Access).

[2] Weishan Zhang, Yue Wang, Xiang Chen, Lingjia Liu, and Zhi Tian, "Collaborative Learning Based Spectrum Sensing Under Partial Observations." IEEE TCCN, 2024 (Early Access).

[3] H. Zheng, K. J. Bai and Y. Yi, "Enabling a New Methodology of Neural Coding: Multiplexing Temporal Encoding in Neuromorphic Computing," in *IEEE Transactions on Very Large Scale Integration (VLSI) Systems*, vol. 31, no. 3, pp. 331-342, 2023

[4] F. Nowshin, Y. Huang, M. R. Sarkar, Q. Xia and Y. Yi, "MERRC: A Memristor-Enabled Reconfigurable Low-Power Reservoir Computing Architecture at the Edge," in *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 71, no. 1, pp. 174-186, 2024