Data Driven Learning and Optimization in Reconfigurable Intelligent Surface Enabled Industrial Wireless Network for Advanced Manufacturing

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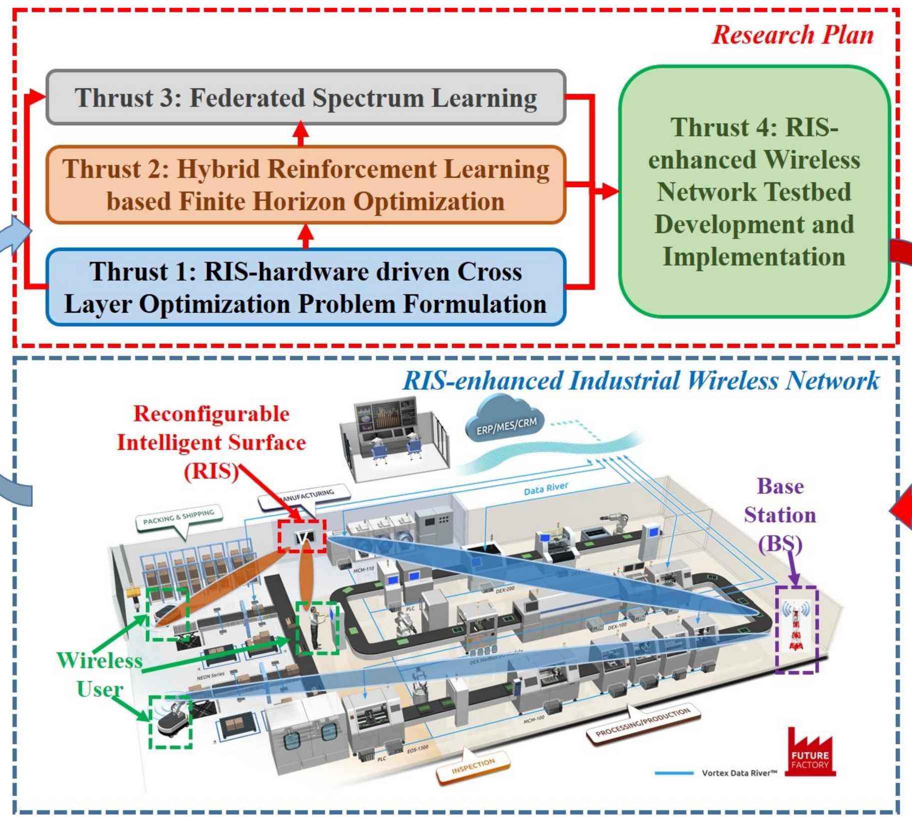
Overview

Project Goal

Address fundamental research challenges required for transcending industrial wireless network from ***theoretical optimistic*** vision to practical and ***implementable reality***.

Technical Objectives

1. **Formulate** a hardware-driven cross-layer optimization problem for RIS-enhanced wireless network with hardware constraints
2. **Design data-enabled learning algorithm** to solve the formulated cross-layer optimization problem
3. **Develop distributed computational efficient learning mechanism** to reduce the network risk during learning
4. **Develop and experimentally characterize** various RIS implementation for wireless networks.



Challenges

1. **Stringent latency requirement** in wireless network for control and automation units in industrial environment
2. **Nonstationary Spectrum sharing** among coexisted mobile users (e.g., mobile robot, human operators) and stationary users (e.g., fixed machinery, etc.).
3. **Dynamic security requirement** for control and automations units in distributed industrial environment

Driving application ***Optimal, Secured, and Dynamic Wireless Network for Industrial 4.0***

A key issue is how to balance optimality, security, time-efficiency in wireless network management that can be used for industrial 4.0 even under dynamic and uncertain industrial environment?

Technical Approach and Results

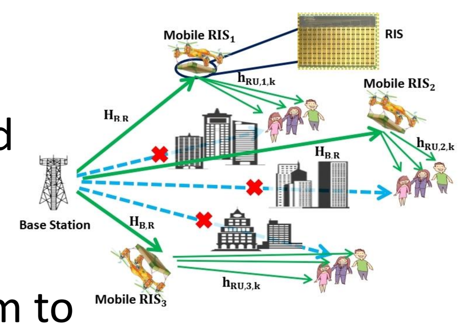
Dynamic resource allocation optimization (A causal RL approach)

Goal: Obtain real-time dynamic optimal resource allocation for time-varying RIS-enhanced network.

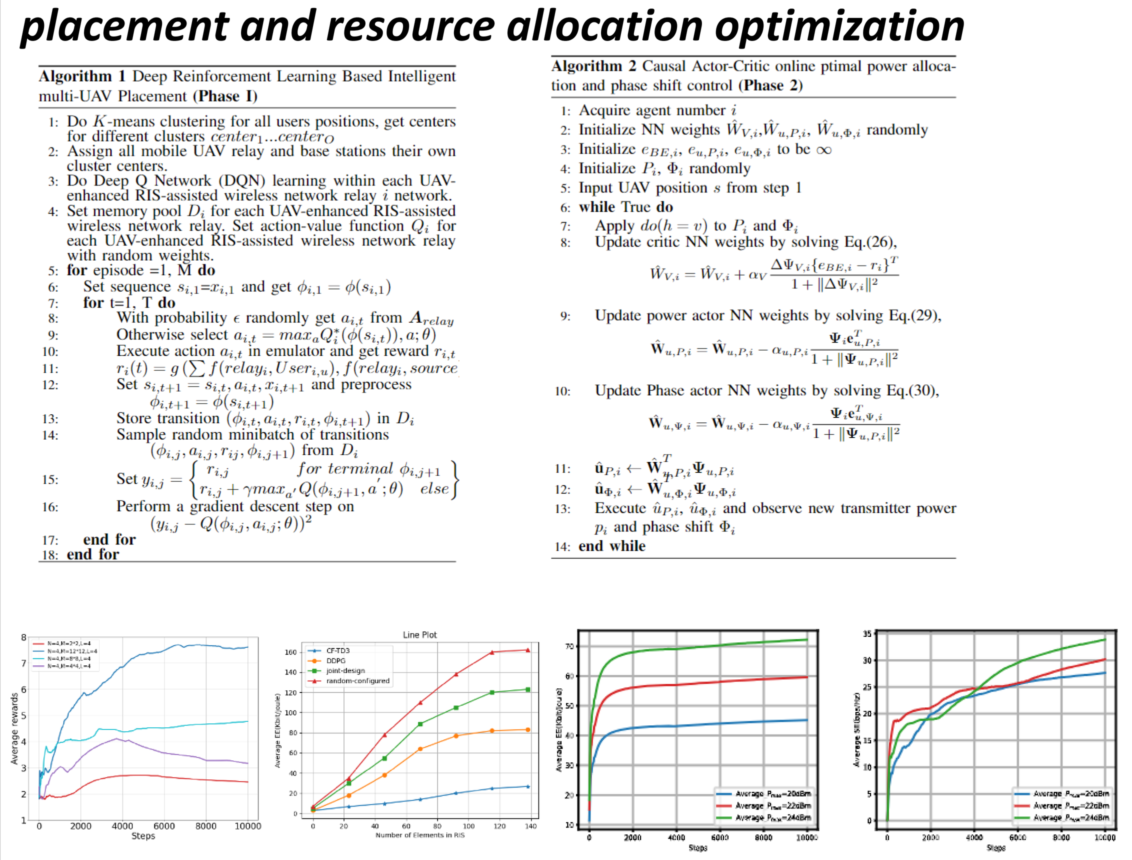
Approach:

Solution 1: Formulate the time-varying dynamic optimization problem for UAV-assisted RIS-aid wireless network.

Solution 2: Develop causal reinforcement learning algorithm to learn dynamic optimal resource allocation online and rapidly.



Causal RL-enhanced Two-phase UAV-assisted RIS placement and resource allocation optimization



(a) Average EE vs. time steps under P_{max} = 20dBm, 22dBm, 24dBm. (b) Average SE vs. time steps under P_{max} = 20dBm, 22dBm, 24dBm.

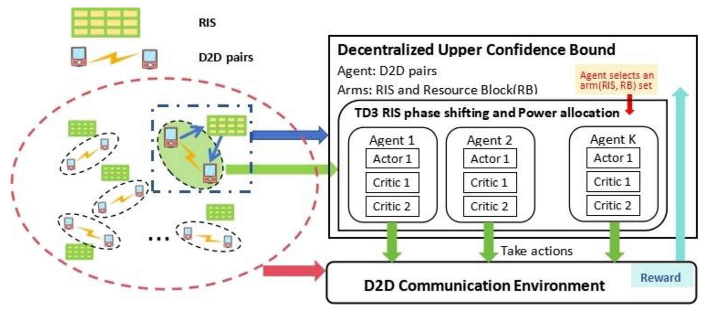
Distributed learning based intelligent resource allocation for multi-RIS-assisted MANET (A multi-player multi-armed bandit approach)

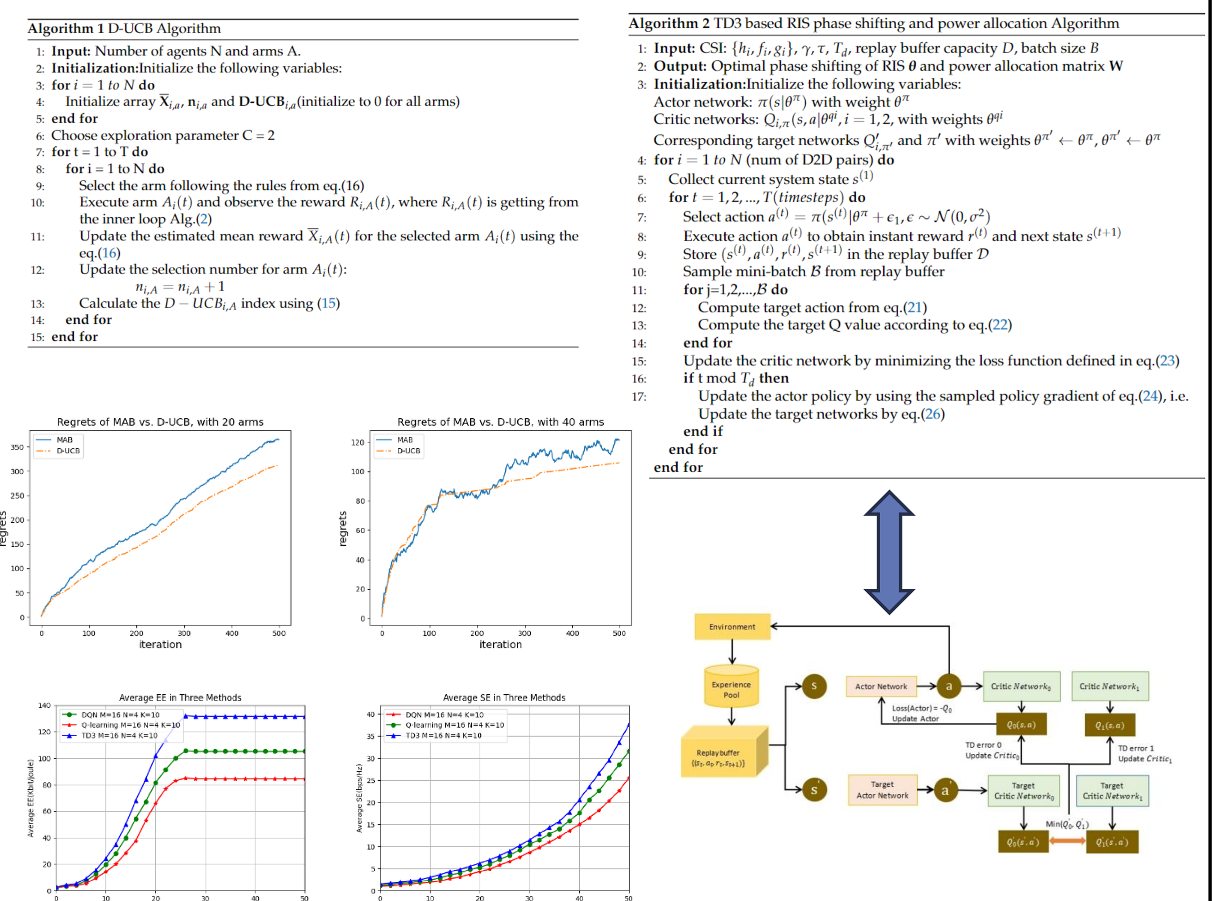
Goal: Obtain intelligent resource allocation for mobile ad-hoc network in a distributed manner.

Approach:

Adopt a multi-player multi-armed bandit approach to handle distributed intelligent resource allocation. Then, use TD3 learning algorithm to solve multi-player MAB.

TD3 distributed learning based intelligent resource allocation for MANET





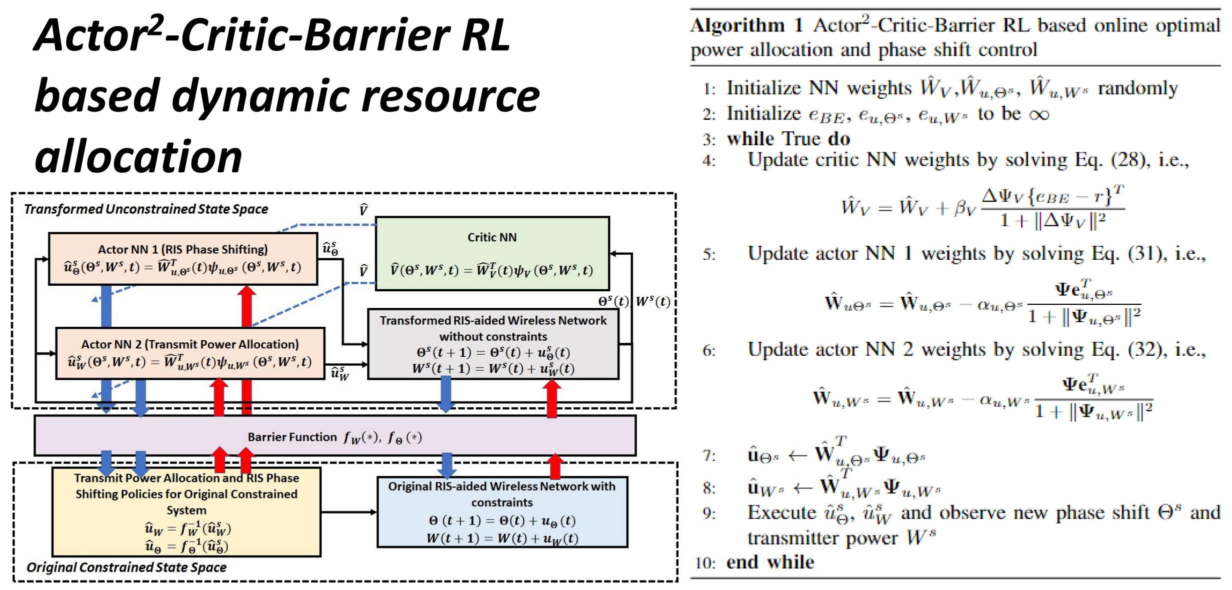
Dynamic resource allocation for RIS-aided MIMO wireless network with hardware limitations (A barrier function approach)

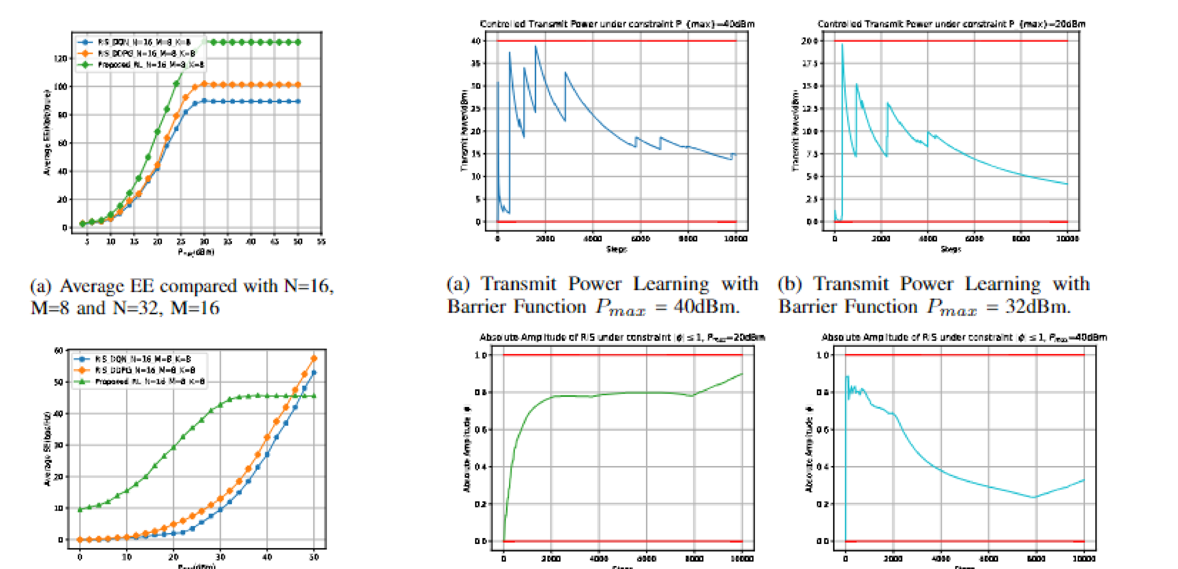
Goal: Obtain feasible cost-effective dynamic resource allocation for RIS-aided MIMO wireless network with limitation from RIS hardware.

Approach:

Adopt a barrier function mechanism and incorporate with actor-critic reinforcement learning (RL) to find dynamic resource allocation for RIS-aided MIMO wireless network with RIS hardware limitations.

Actor²-Critic-Barrier RL based dynamic resource allocation





(a) Average EE compared with N=16, M=8 and N=32, M=16

(a) Transmit Power Learning with Barrier Function $P_{max} = 40$dBm. (b) Transmit Power Learning with Barrier Function $P_{max} = 32$dBm.

(b) Average SE compared with N=16, M=8 and N=32, M=16

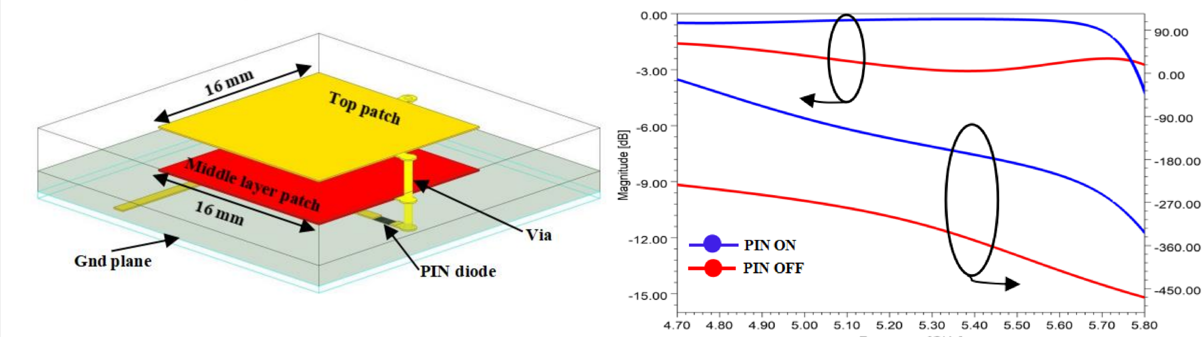
(a) RIS phase Learning with Barrier Function $|\phi| \leq 1$, $P_{max} = 40dBm$. (b) RIS phase Learning with Barrier Function $|\phi| \leq 1$, $P_{max} = 20dBm$.

RIS Hardware development and wireless system testbed

Goal: Design a wideband binary RIS surface at Sub-6 band, and use it for RIS-assisted wireless communication system test.

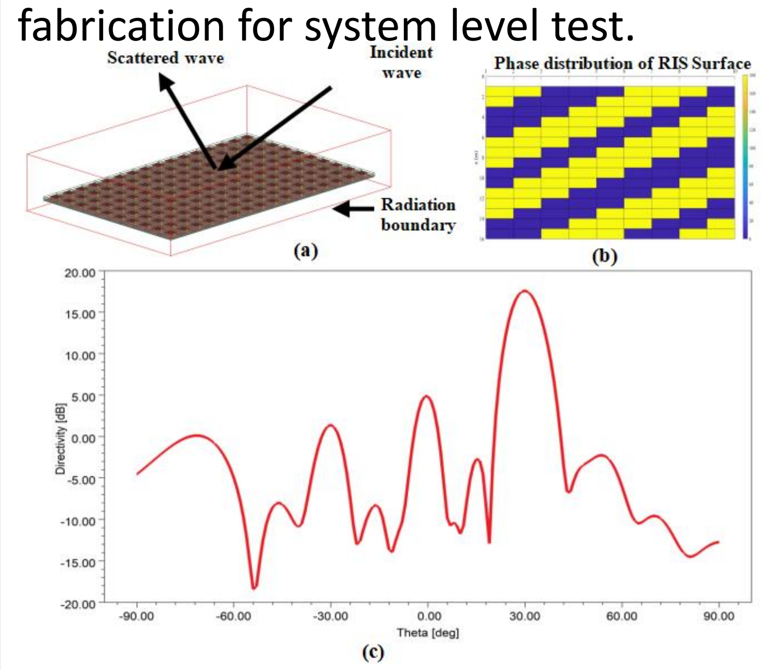
Approach:

A two-layer stacked patch structure is used to broaden the bandwidth of the RIS element. A 1-bit PIN diode is employed to reconfigure the phase states, and a phase difference of is observed over the frequency range of 4.81 – 5.77 GHz, a 19.2% fractional bandwidth.

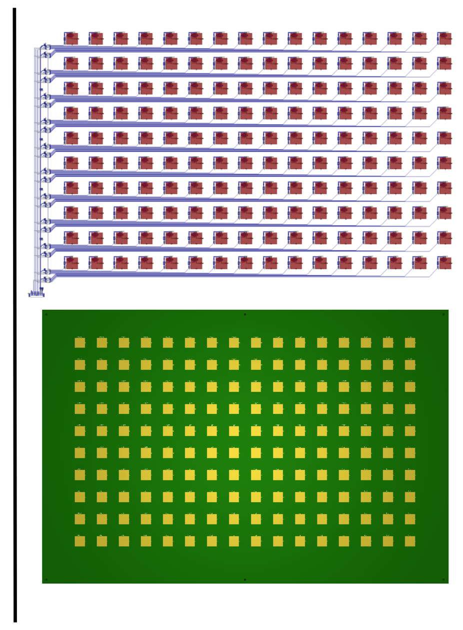


(a) RIS unit element (b) phase/magnitude response

For system level test, a 16x10 array is designed and has been verified for its beamforming capability. A prototype is under fabrication for system level test.



Beamforming capability verification



RIS array surface design

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Selected Products

1) Yuzhu Zhang, and Hao Xu. "Optimal Dynamic Resource Allocation for Multi-RIS Assisted Wireless Network: A Causal Reinforcement Learning Approach ". In *2024 International Conference on Computing, Networking and Communications (ICNC),* 2024.

2) Yuzhu Zhang, and Hao Xu. "Decentralized Learning based Optimal Design for RIS –assisted Multi-user Ad-Hoc Network: A Multi-Player Multi-Armed Bandits Approach." In 2024 *International Conference on Computing, Networking and Communications (ICNC),* 2024.

3) Zhang, Yuzhu, Lijun Qian, and Hao Xu. "Joint Optimal Placement and Dynamic Resource Allocation for multi-UAV enhanced Reconfigurable Intelligent Surface Assisted Wireless Network." In *2023 International Conference on Computing, Networking and Communications (CCNC)*, pp. 1-6. IEEE, 2023.

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