Reconfigurable Radio Environments for Next-Generation AI Infrastructure

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Overview: Programmable Wireless Environment

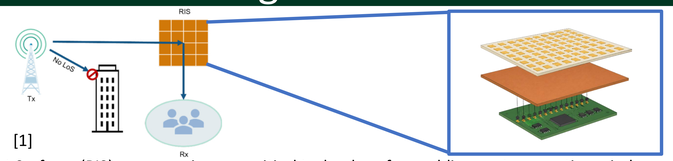


Figure 1. RIS-assisted communication redirects wireless signals around obstacles to improve connectivity.

[1]

Figure 2. Multilayer RIS architecture integrating a programmable RF surface and digital control electronics.

Reconfigurable Intelligent Surfaces (RIS) are emerging as a critical technology for enabling next-generation wireless systems, including 6G networks, Low-Earth-Orbit (LEO) satellite communications, and the rapidly growing connectivity demands of distributed AI infrastructure. As future wireless systems increasingly utilize higher-frequency bands to achieve greater bandwidth and data rates, they also face significantly higher propagation losses, increased sensitivity to blockage, and reduced coverage.

RIS devices address these challenges by transforming the wireless environment into a reconfigurable radio environment that can actively shape signal propagation. By dynamically controlling the electromagnetic response of individual surface elements, RIS can redirect and shape wireless signals to improve coverage, reliability, and energy efficiency. A major challenge, however, is determining the optimal phase configuration of potentially hundreds or thousands of RIS elements. Our work explores hardware-efficient intelligent control of RIS using FPGA-based acceleration, which provides a low-latency platform for deploying AI and optimization algorithms for the wireless system.

By combining programmable radio environments with FPGA-based intelligence, this work investigates a path toward adaptive wireless infrastructure capable of responding to changing channel conditions in real time. Such systems have the potential to support future 6G networks, satellite communications, edge AI, and the increasingly distributed compute and communication infrastructure required by next-generation AI systems.

Motivation and Research Objectives

Why RIS?

High-Frequency Connectivity
Supports emerging mmWave and beyond-5G applications.

Blockage Mitigation
Redirects signals around obstacles and limited line-of-sight paths.

Energy-Efficient Control
Enables propagation control using electronically configurable surfaces.

Spectral Efficiency
Improves wireless channel conditions and spectrum utilization.

Emerging Applications
6G, LEO satellites, edge AI, and distributed infrastructure.

Research Objective:
Can AI-assisted hardware efficiently control Reconfigurable Intelligent Surface (RIS) in dynamic radio environments?

RIS enables programmable wireless environments for future 6G, edge AI, and satellite communications.

By making wireless propagation programmable, RIS introduces new opportunities to integrate communication systems with intelligent computing infrastructure. This approach could improve connectivity for distributed computing resources while reducing reliance on additional transmission infrastructure.

RIS Physics

Programmable Reflection

$$\Gamma_n = |\Gamma_n| e^{j\phi_n}$$

Each RIS element controls the amplitude and phase of reflected electromagnetic waves.

Beam Steering via Phase Gradient

$$\Delta\phi \rightarrow \theta_r$$

A spatial phase gradient across the RIS controls the reflected beam direction.

PIN diodes reconfigure RIS elements by switching between different RF impedance states. These changes modify the reflected signal's phase and amplitude, enabling programmable beam steering.



(a) $\theta = 0°, \phi = 0°$.



(b) $\theta = 80°, \phi = 0$.

Figure 3: Simulated radiation patterns illustrating RIS beam steering at different reflection angles.

[2]



Figure 4: Theoretical and measured received power versus the number of RIS elements.

The effectiveness of an RIS depends on element spacing, operating frequency, reflection losses, and the number of available phase states. Practical implementations must balance electromagnetic performance with switching complexity, fabrication constraints, and hardware cost. AI-assisted control optimizes RIS element states to dynamically steer reflected electromagnetic waves.

RIS Control Scaling

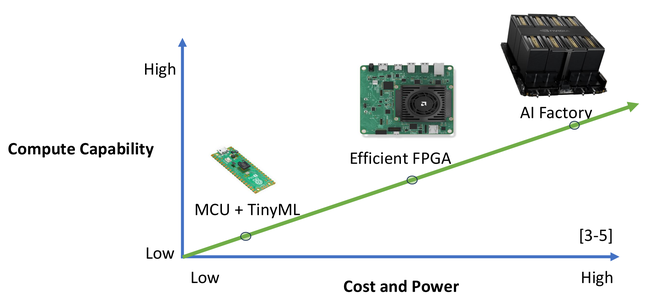


Figure 6. RIS control hardware scales from microcontrollers to FPGAs and AI infrastructure, with platform selection based on application-specific requirements.

Increasing capability enables:
- Larger RIS arrays
- Advanced AI Models
- Higher mobility scenarios

Selecting a computing platform requires balancing inference latency, power consumption, cost, and available computational resources. While microcontrollers provide accessible prototyping, FPGAs support deterministic parallel processing, and AI factories provide resources for large-scale model training and simulation.

AI-Driven RIS Control Architecture

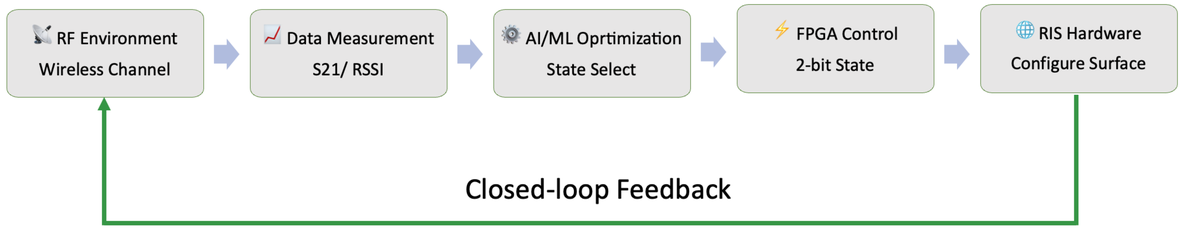


Figure 5. Proposed architecture integrating convolutional neural network (CNN)-based RIS optimization, FPGA control, and closed-loop feedback using S21 or Received Signal Strength Indicator (RSSI) measurements.

An RIS with N independently controlled elements and four states per element has 4^N possible configurations. For a 10 × 10 array, this corresponds to approximately $1.61 * 10^{60}$ configurations, making exhaustive search computationally impractical. CNN-based optimization offers a promising approach for predicting effective RIS configurations without evaluating every possible state.

Current Architecture and Next Steps

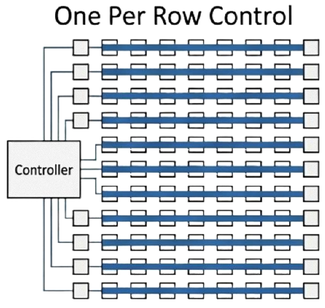
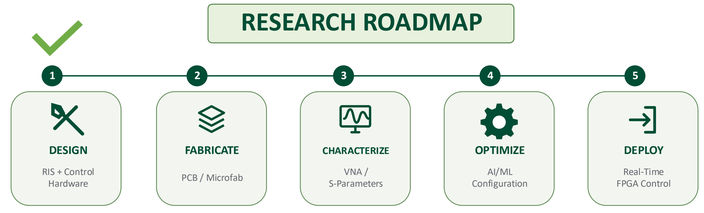


Figure 7. Proposed row-level addressing architecture for digital RIS configuration.



The research integrates hardware development, RF characterization, and AI-driven optimization into a complete RIS system. Experimental measurements will inform CNN-based configuration prediction, with FPGA deployment enabling real-time adaptive control.

The proposed control architecture must balance the number of independently configurable elements against routing complexity, control latency, and power consumption. Future evaluation will investigate these tradeoffs through hardware characterization and comparison of control strategies.

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