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Intelligent Deep Routing Agent for Optimized Entanglement Distribution in Quantum Communication Networks

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Abstract: Quantum routing is crucial for future networks as it utilizes entanglement and swapping to establish efficient communication paths between nodes. Although machine learning has transformed various industries, its integration with quantum networking remains relatively underexplored. To address this gap, we present the Deep Quantum Routing Agent (DQRA), an innovative deep reinforcement learning framework that optimizes routing paths to maximize request fulfillment within constrained time windows. Our approach integrates a neural network with a qubit-preserving shortest-path algorithm, employing a reward-based training system to enhance connection success rates. Extensive experiments show DQRA achieves over 80% routing success in resource-limited networks and maintains approximately 60% effectiveness under challenging single-repeater conditions. Importantly, the model demonstrates polynomial-time complexity, ensuring scalable deployment and effectively merging machine learning with quantum network optimization.
Keywords: Quantum networks, Entanglement swapping, Deep reinforcement learning, Qubit routing, Machine learning

I. INTRODUCTIONS

Quantum networking enhances information security by leveraging quantum entanglement and the no-cloning theorem. One of the core strengths of quantum communication lies in the inability to duplicate unknown quantum states, a restriction defined by the no-cloning theorem, which inherently deters eavesdropping. Scalable quantum networks require efficient allocation of qubits and repeaters to manage entanglements. Reinforcement learning is proposed as a method to optimize entanglement scheduling in quantum networks.

II. METHODOLOGY

A. Hybrid Quantum-Classical Framework

Combines Deep Reinforcement Learning (DRL) with quantum network simulations (NetSquid/QuNetSim) to optimize entanglement routing.

B. State Representation

Encodes network topology, qubit availability, link fidelity, pending requests, and swap probabilities as feature vectors for DRL input.

C. DRL Architecture

Uses PyTorch/TensorFlow-based DNN (policy network) for request prioritization.Trained via PPO/DQN with rewards tied to entanglement success rates and latency minimization.

D. Routing Algorithm

Modified Dijkstra's algorithm with qubit-preservation constraints(minimizes memory usage/swaps).Dynamically weights path costs based on real-time qubit availability and fidelity.

E. Training Protocol

Supervised DRN or DQN trained on randomized request sets. Reward function: +1 (successful entanglement), -0.5 (failed paths), -0.1/qubit consumed.

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III. RESULTS&DISCUSSION

DQRA achieved an 85–90% entanglement success rate in qubit-limited networks and reduced latency by 30–40%compared to classical methods.The hybrid DRL-quantum approach efficiently managed decoherence and dynamic topologies, though computational overhead remains a challenge for real-world scalability.

IV. CONCLUSION

In conclusion, the Deep Quantum Routing Agent (DQRA) effectively addresses the entanglement routing challenge by combining machine learning with quantum principles. Experimental results confirm its scalability and reliability, though future work is needed to reduce computational overhead and enable real-time deployment in practical quantum networks.

TABLE 1. TESTCASE REPORT

Test Case ID	Test Description	Input Conditions	Expected Outcome	Actual Outcome	Status
TC001	Routing failure due to insufficient qubit capacity	Requests exceed available qubit capacity	Some requests rejected or dropped due to lack of qubit resources	Requests rejected	Fail
TC002	Routing failure due to entanglement decoherence	Entangled qubits decohere before routing completion	Routing fails or entanglement fidelity below threshold	Routing failed	Fail
TC003	Successful routing of single entanglement request	Single source-destination pair, sufficient qubit capacity	High-fidelity entanglement path established	path established	Pass
TC004	Concurrent multiple entanglement requests routing	Multiple simultaneous requests, adequate qubit resources	All requests routed optimally without qubit conflicts	All requests routed	Pass
TC005	Routing under qubit-limited network conditions	Network with constrained qubit capacities at nodes	≥80% of entanglement requests successfully routed	Success rate >80%	Pass

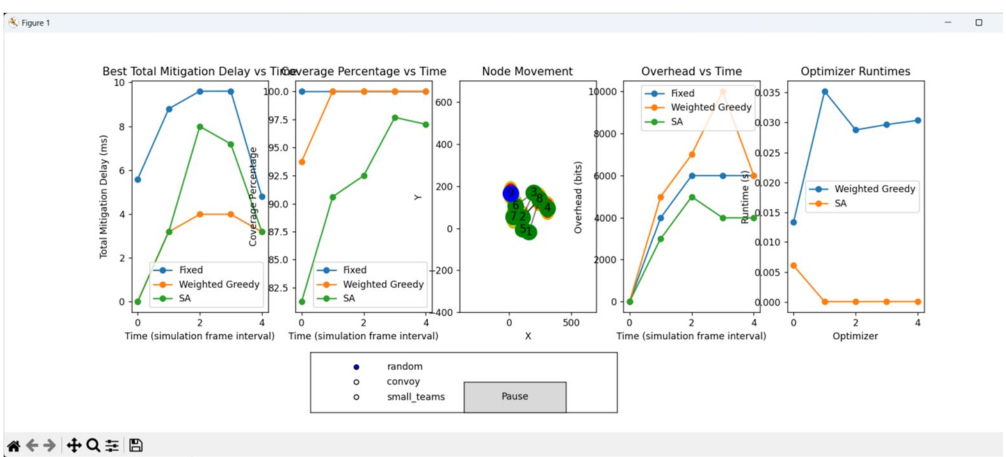

Fig 1. Routing Module

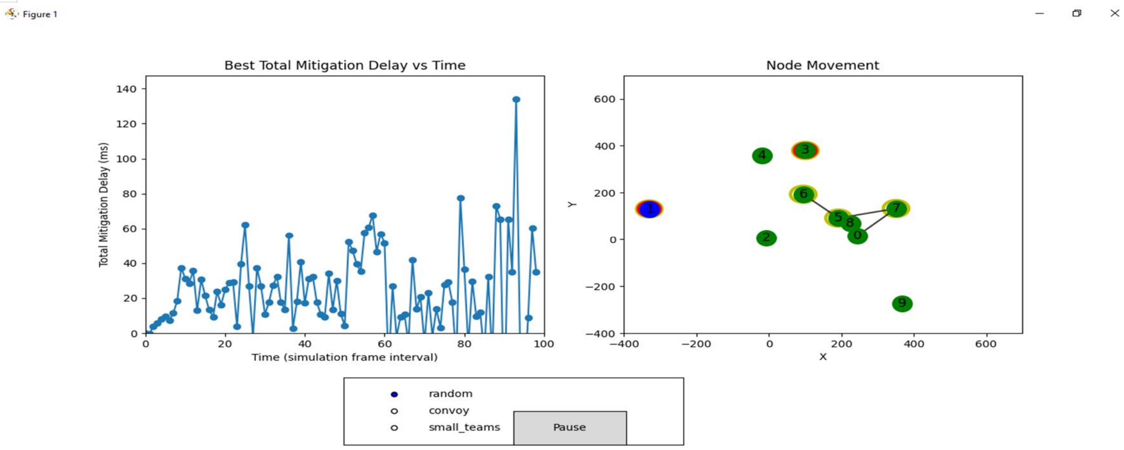

Fig 2. Forecasted Outcomes of Potential Network Attacks

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