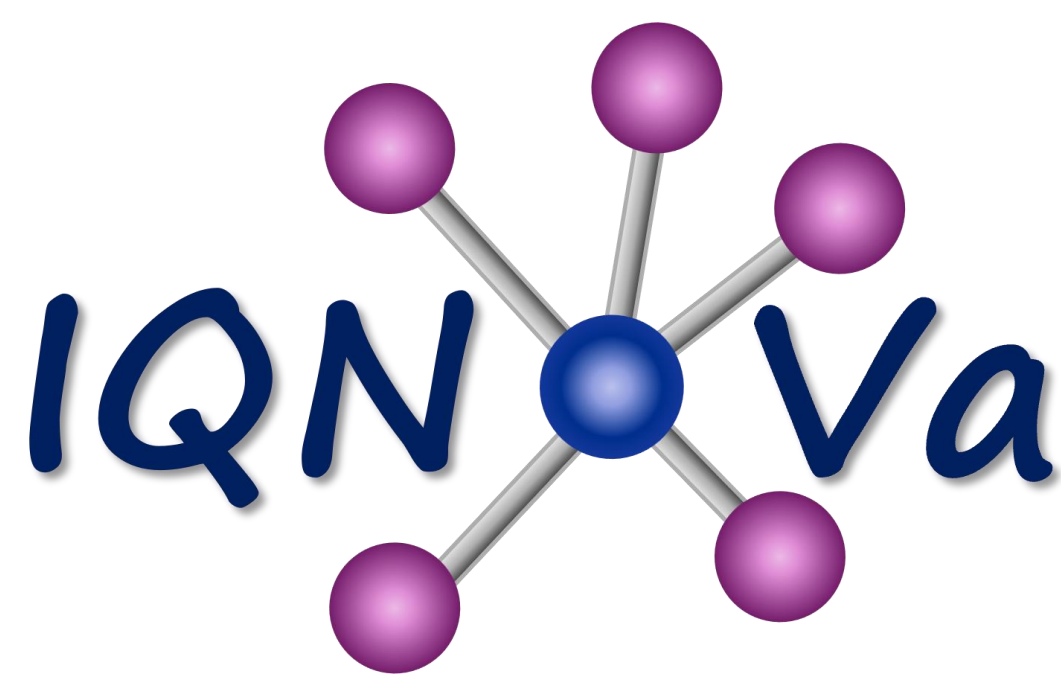




Benchmarking and Validation of Interconnected Quantum Nodes



Orsolya Kálmán¹ · Matthias Müller² · Durga Dasari³ · Zoltán Zimborás⁴ · Sabrina Maniscalco⁵

¹HUN-REN Wigner Research Centre for Physics

²Forschungszentrum Jülich

³University of Stuttgart

⁴University of Helsinki

⁵Algorithmiq Ltd.

How well does an interconnected quantum system perform as one distributed computational resource?

Why network benchmarks?

A quantum network succeeds only when local operations, memories, photonic links, classical communication and timing work together. Node and link specifications alone cannot predict whether a distributed task will complete with useful fidelity.

Existing metrics miss interactions between

- local gate and measurement errors
- memory decoherence during probabilistic entanglement generation
- routing, synchronization and network topology
- error propagation across remote operations

IQNoVa objectives

- Characterize errors and validate protocols at node and link level
- Demonstrate benchmarking and control on modular spin-qubit nodes
- Establish topology-aware metrics for multi-node systems

Research questions

Which measurements predict remote-gate and distributed-task performance?

How should benchmarks account for probabilistic and asynchronous network processes?

Which resources and topologies provide a practical advantage?

Methodology

Node level

Separate contributions from local gates, state preparation and measurement, entanglement generation, Bell measurements and synchronization. Extend randomized-benchmarking ideas to shared entanglement and teleportation-based operations.

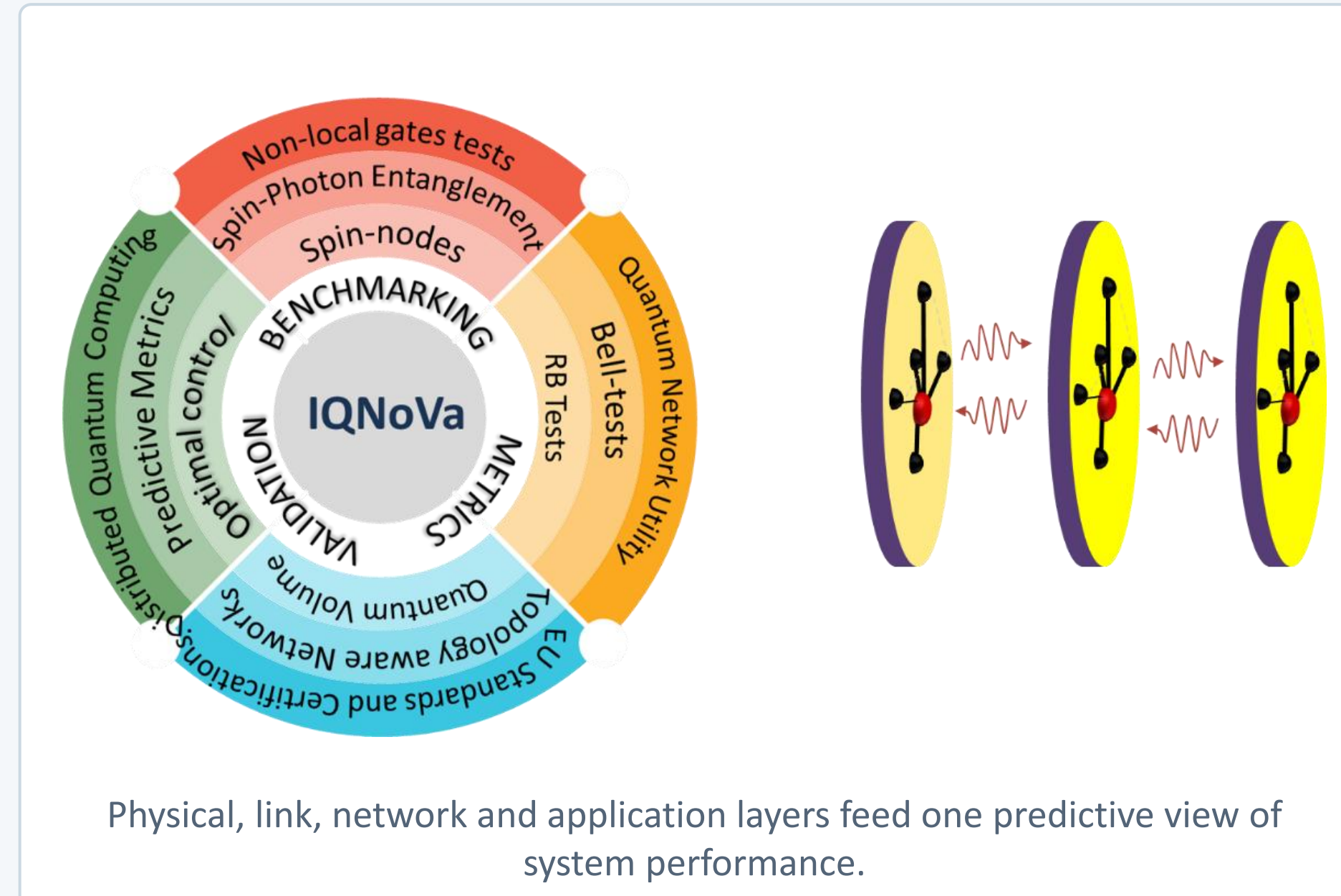
Network level

Combine measured node and link parameters with memory coherence, routing and topology. Evaluate remote-gate success, multipartite-state fidelity, entanglement-distribution rate and distributed computational throughput.

Resource-aware protocols

Use entanglement distillation to relate noisy Bell or multipartite states to the fidelity and resource cost of non-local operations.

A multi-layer validation framework



Closed theory–experiment loop

Measured hardware parameters refine the models. Network requirements guide pulse design, local operations and inter-node protocols. Each iteration makes the benchmarks more predictive and experimentally practical.

Experimental validation

Platform

Silicon-vacancy (V2) centres in 4H-SiC provide optically addressable electron spins coupled to nearby nuclear-spin memories. Spin-dependent optical emission offers a route to photonic links between remote nodes.

Experimental programme

- characterize one- and two-qubit operations
- map register connectivity and crosstalk
- improve operations with quantum optimal control
- benchmark spin-photon-mediated inter-node entanglement

Expected outputs

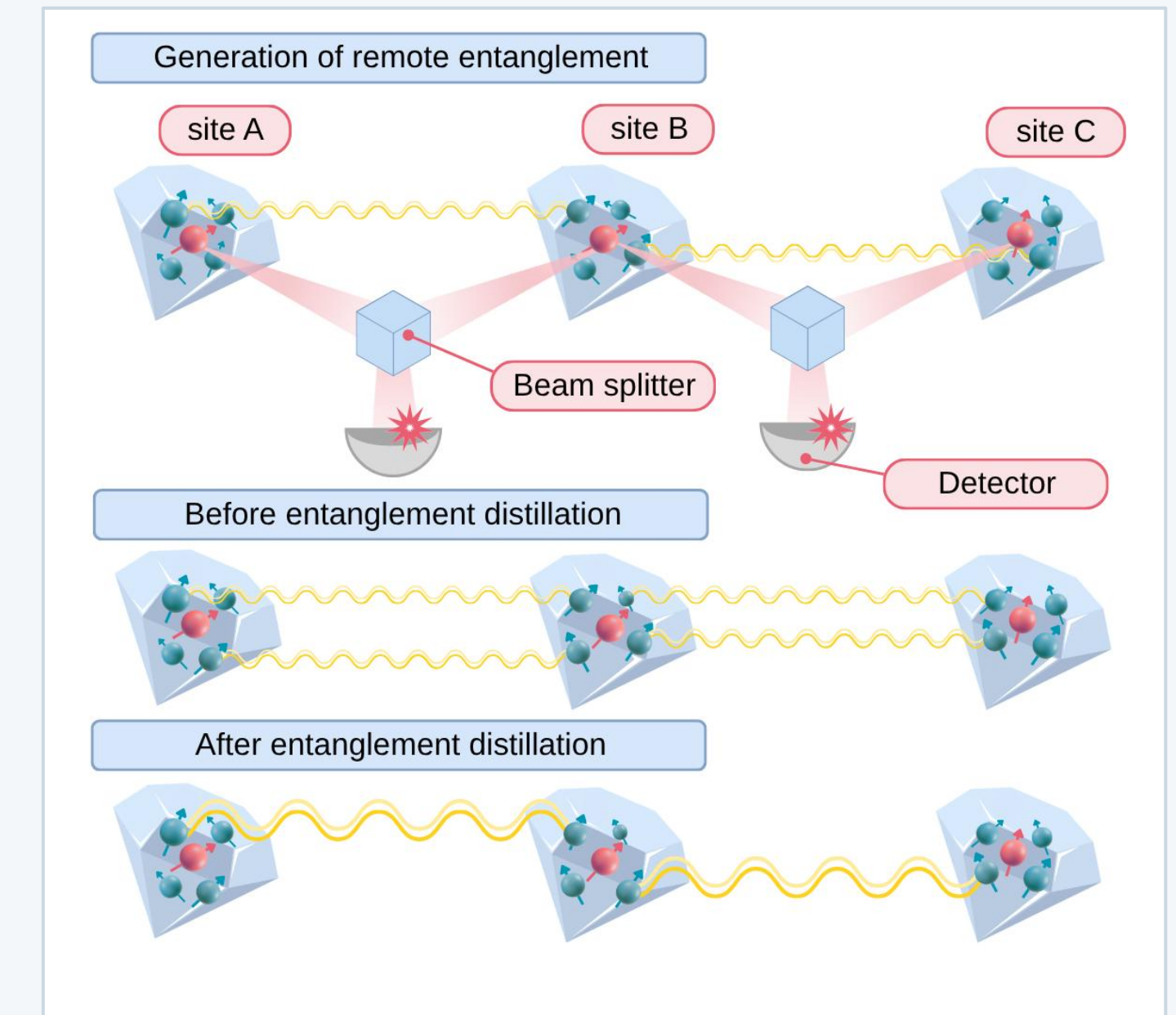
- experimentally implementable network benchmarks
- topology-aware predictive performance metrics
- quantitative validation on spin-based nodes
- open-source software for distributed-system characterization

Why it matters

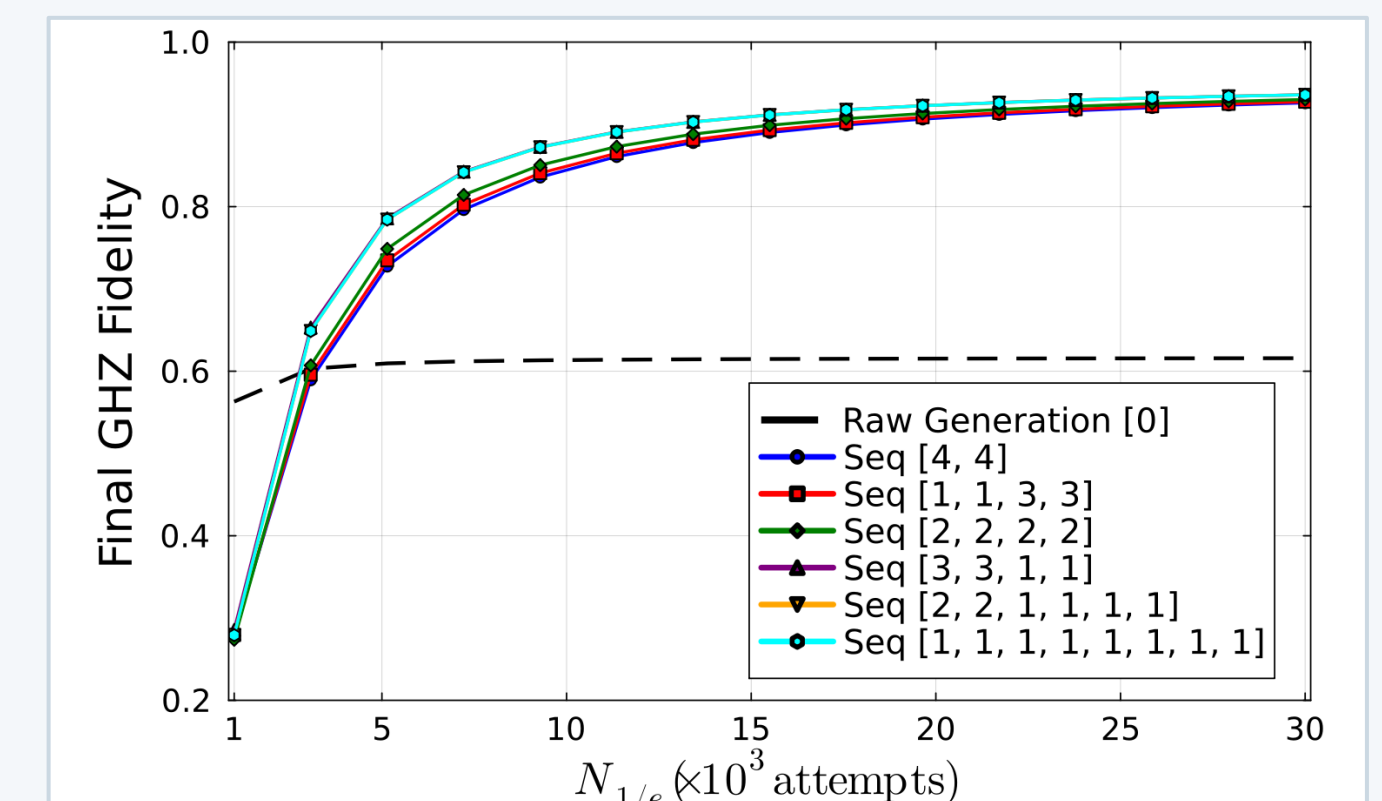
IQNoVa will connect component-level errors to complete distributed tasks. The resulting methods can reveal bottlenecks, guide hardware and software design, and support reproducible comparisons between architectures.

Preliminary results on interconnected nodes

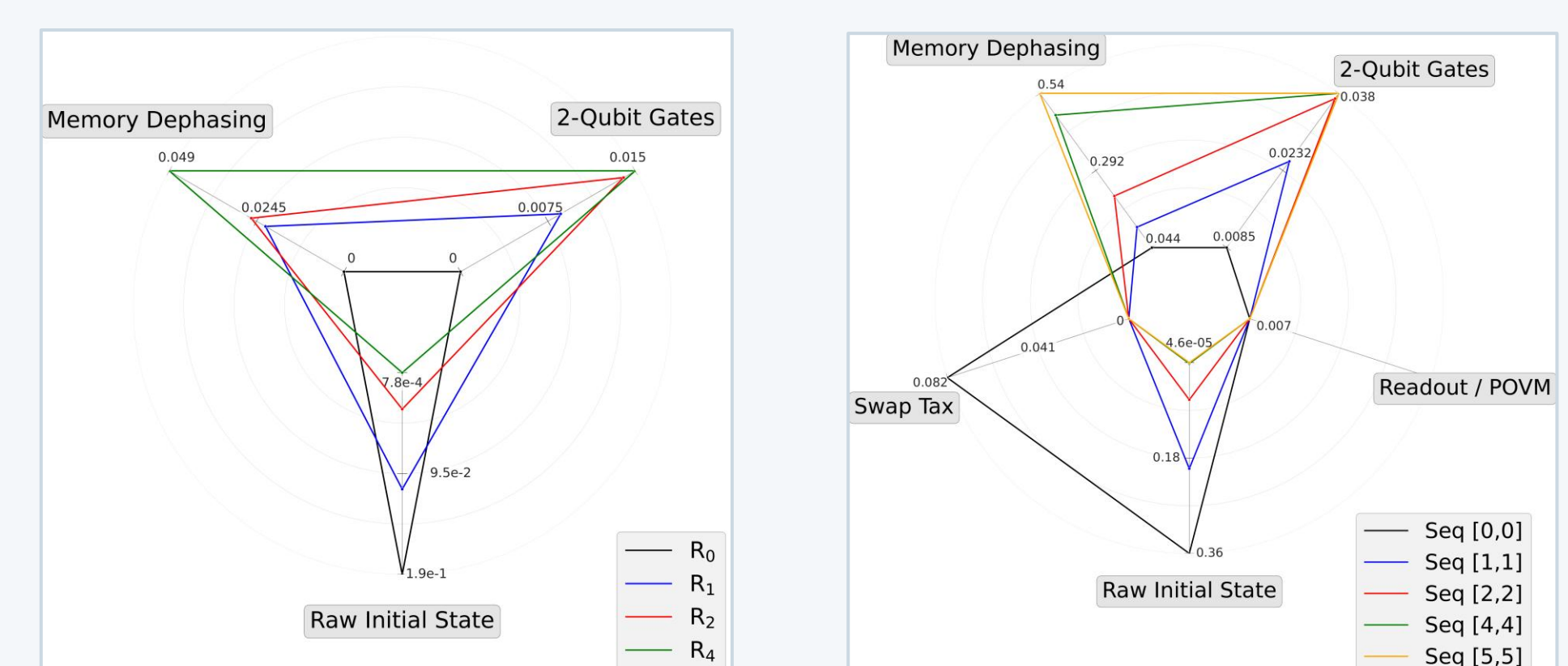
We investigated repeated entanglement distillation in small color-center quantum networks, accounting for finite qubit resources, synchronization between network links, and experimentally relevant imperfections including dephasing and gate errors.



- We analyzed different distillation strategies for the generation of high-fidelity Bell and GHZ states



- We analyzed their performance using parameters reported for nitrogen-vacancy centers and group-IV defects in diamond



Selected references

- [1] Knill et al., Phys. Rev. A 77, 012307 (2008).
- [2] Hashim et al., PRX Quantum 6, 030202 (2025).
- [3] Helsen and Wehner, npj Quantum Inf. 9, 17 (2023).
- [4] Lee et al., PNAS 121, e2314103121 (2024).
- [5] Pompili et al., Science 372, 259 (2021).
- [6] Knaut et al., Nature 629, 573–578 (2024).
- [7] Hesselmeier et al., Phys. Rev. Lett. 132, 180804 (2024).

Long-term impact

Vendor-neutral metrics and common workflows can contribute to interoperability and future standardization of distributed quantum technologies.

Project partners



Funding



PROGRAM FINANCED FROM THE NRDI FUND

With funding from the:



IQNoVa is funded under the QuantERA Call 2025 with support from NKFIH (Hungary), BMFT (Germany) and the Research Council of Finland (AKA).