Fast, almost classical, and Bell-pair aware quantum backend

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Description

Quantum computing promises performance and security beyond classical applications. For instance for synchronous consensus problem against full information adaptive adversary, quantum solutions are known to reach $O(1)$ expected round complexity [1], while the best classical solutions had lower bounds of $\Omega(n/\log(n))$. Since the cost of building quantum network infrastructure is enormous, the use of quantum network simulators such as SeQUeNCE [2] to evaluate the behavior of distributed quantum protocols is unavoidable.

To be useful for general quantum computations, the internal representation of quantum state of such simulators is either expensive (density matrices) or cannot (stabilizers) represent mixed quantum states that arise from depolarization noise. As a result, once the number of entangled qubits gets high, the resource requirements for the simulation increase rapidly. For instance, the [1] follow-up work that improves on communication complexity by relying on [3] results in multiple nodes entangled together, and that gets worse with every gossiping step. What is particular, though, about both coordination algorithms is that they use only a limited subset of quantum operations, namely, then never change phase, which opens up optimization opportunities.

Goal

The goal of this project is to implement a `QuantumManager` "backend" for SeQUeNCE simulator that will: a) enable quantum versions of classical gates used by coordination algorithms; b) faithfully model entanglement distribution protocols, distillation in particular. Thus the representation should support Bell-diagonal [4] representation for 2-qubit states and switch to probabilistic distribution over classical state when more qubits are in play.

Objectives

- Refresh quantum state representation (vector state + density matrices) [5]
- Understand the interfaces employed by [2] (including `QuantumManager`)
- Implement a baseline for propagating gossip over a sequence of nodes [3]
- Make adjacent nodes in the chain use a single round of DEJMPS distillaion [4]
- Design a `QuantumManager` supporting Bell-diagonal and classical mixtures
- Validate the performance improvements against the baseline

Expected results: Simulate [3] gossip over a sequence of nodes with distill [4]

Prerequisites

- Python
- Linear algebra

References

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