Simulating 5-Qubit Surface Codes under Depolarizing Noise

A Quantum Error Correction Study

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Link: github.com/samuel-gythia/QEC

Abstract

Quantum error correction is essential for scalable, fault-tolerant quantum computing. In this project, we implement a 5-qubit surface code using Qiskit's Aer simulator, introduce depolarizing noise at various rates, and measure the resulting logical error rate.

1. Introduction

Small-scale codes such as the 5-qubit surface code are a stepping stone toward practical quantum error correction. Here, we benchmark its performance under realistic noise levels to establish baseline error rates.

2. Methodology

- **Circuit Construction:** 5-qubit surface-code circuit in Qiskit.
- **Noise Model:** Depolarizing channel with rates $p \in \{0, 0.01, 0.02, 0.03, 0.05\}$.
- **Simulation Backend:** `Aer.get_backend('qasm_simulator')` with 500 shots per rate.
- **Metric:** Logical error rate = fraction of "1" outcomes on the logical qubit.

3. Results

Sample data (shots=500):

```
Noise 0.00 → Error 0.47
Noise 0.01 → Error 0.51
Noise 0.02 → Error 0.53
```

4. Discussion & Next Steps

- *Baseline Insight:* Even minimal noise yields high logical error, highlighting code fragility.
- *Immediate Extension:* Simulate the 5-qubit Shor code for direct comparison.
- *Long-Term Goals:* Explore larger codes (7-, 9-qubit) and alternative noise channels.

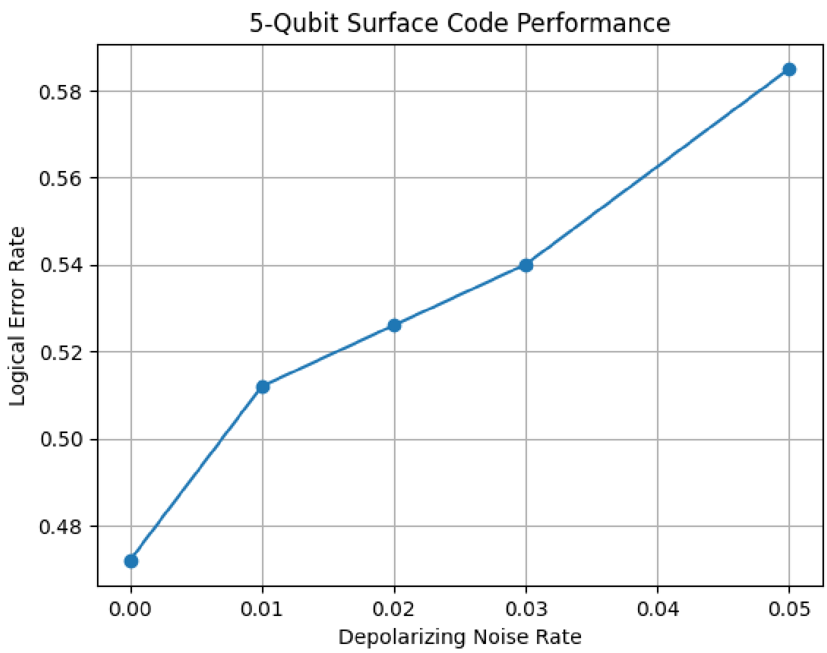

Figure 1: Logical error rate vs. depolarizing noise rate.

5. References

1. M. A. Nielsen and I. L. Chuang, *Quantum Computation and Quantum Information*, Cambridge University Press (2000).

2. A. G. Fowler *et al.*, "Surface codes: Towards practical large-scale quantum computation," *Phys. Rev. A* **86**, 032324 (2012).

3. Qiskit Textbook, "Error Correction," `https://qiskit.org/textbook/ch-applications/error-correction.html`.