Quantum Computing Chip with Error-Correction Encoding

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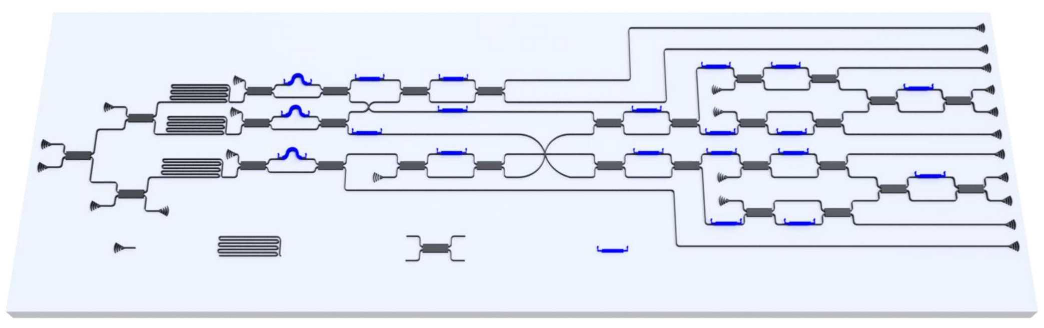
INTRODUCTION AND OBJECTIVES

Quantum error correction is a scheme to encode the quantum information in a more complex state to protect it against noise and decoherence. When the information is corrupted by noise, we can retrieve it from the redundant states instead of losing it, thus improving the fidelity of qubits and operations. Cluster state is a highly entangled resource that its stabilizer constitutes a sufficient backbone for fault-tolerant quantum computation with many error-correction codes built on it. We demonstrate an error-correction encoding scheme that can tolerant a single qubit error at known location on silicon photonic platform and achieve a state fidelity of 86% for the reconstructed logic qubit. This scheme can be further applied to a fault-tolerant one-way computing to remove the failed operation and reconstruct the quantum teleportation channel between qubits.

DESIGN SCHEMATIC



Schematic of photonic integrated chip for error-correction. The single photon is generated on chip via the SFWM and the quantum state is encoded and measured in the linear optical circuit part.

ERROR-CORRECTION ENCODE

A single logic qubit $|\psi\rangle_L = \alpha|0\rangle_L + |1\rangle_L$ is encoded with 4 physical qubits as

$$|0\rangle_L = (|00\rangle + |11\rangle)(|00\rangle + |11\rangle) = |\phi^+\phi^+\rangle$$
$$|1\rangle_L = (|00\rangle - |11\rangle)(|00\rangle - |11\rangle) = |\phi^-\phi^-\rangle$$

A 3-photon 3-qubit GHZ state

$$|000\rangle + |111\rangle$$

is first prepared on chip by post selection.

Then the last two photons are each expanded into 4 waveguides to map to a 2-qubit space as

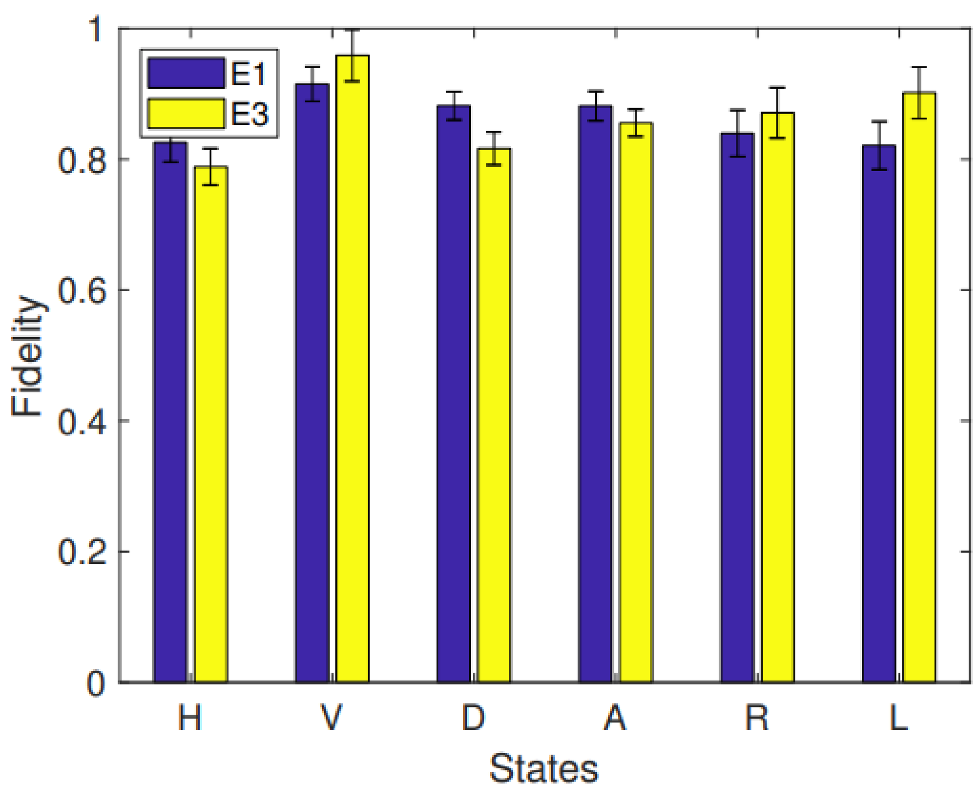
$$|L_5\rangle = |0\phi^+\phi^+\rangle + |1\phi^-\phi^-\rangle$$

which is a 5-qubit linear cluster state.

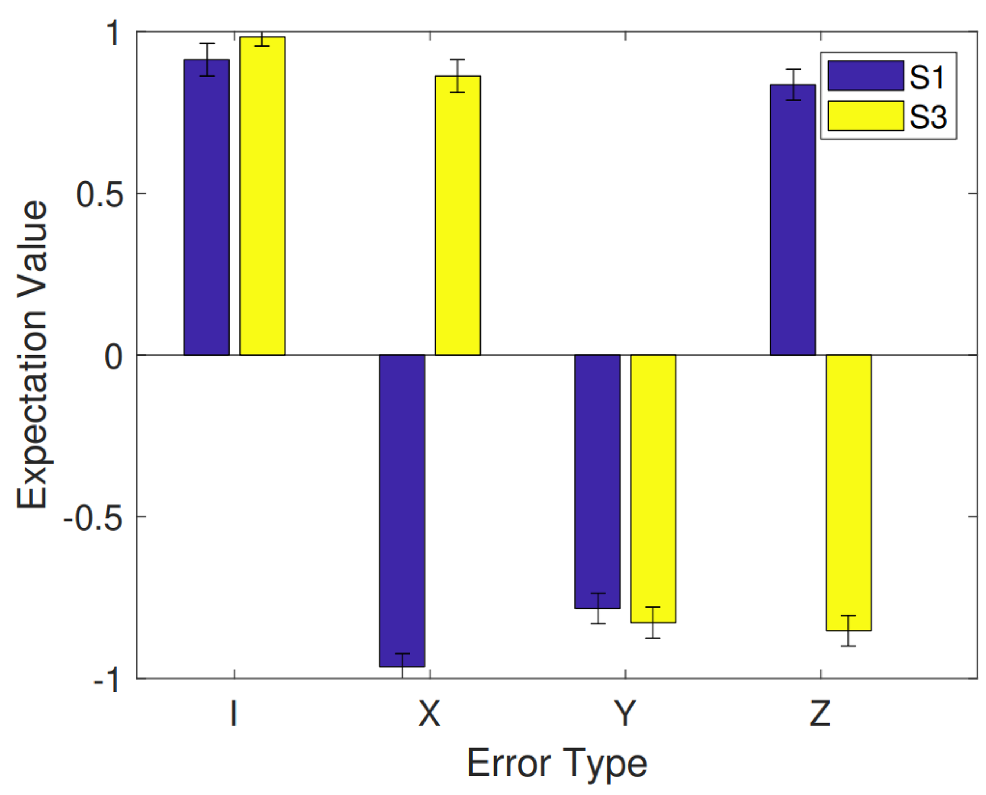
By measuring the first qubit under specific basis, the logic qubit is encoded with 4 physical qubits as

$$|\psi\rangle_{1234} = \alpha|\phi^+\phi^+\rangle + \beta|\phi^-\phi^-\rangle$$

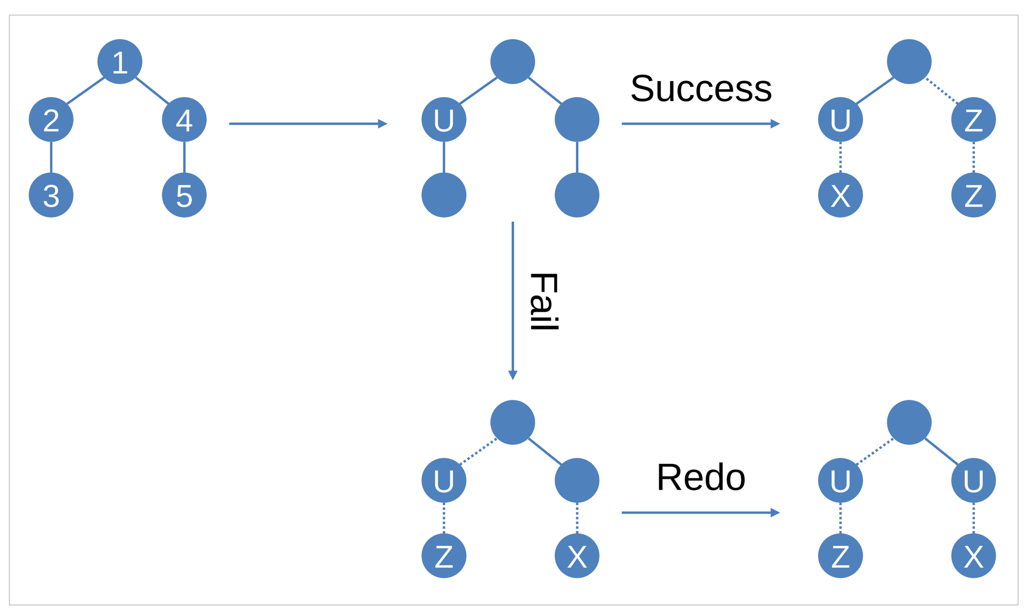
TESTING RESULTS



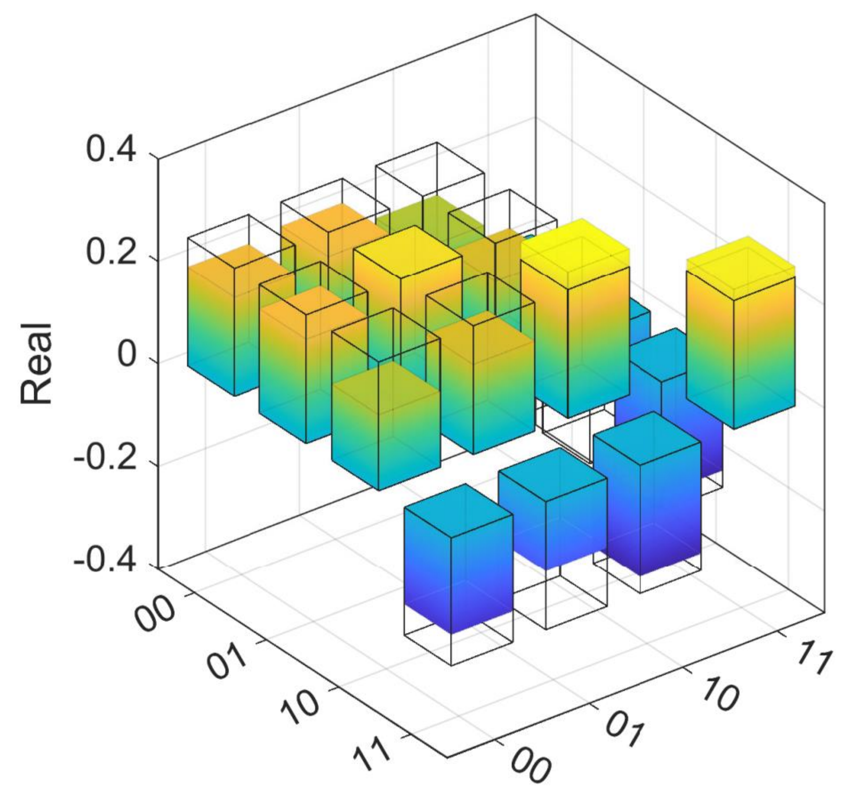
The reconstructed state fidelity from errors. X axis represents the initial logical qubit. Blue and yellow bars each represents the error location at 1st qubit and 3rd qubit. An average fidelity of $F = 0.8630$ is achieved.



Stabilizer expectation value can be used to identify the error types at the known location. The figure shows the measured expectation value for stabilizer S_1 and S_3 at qubit 1 and corresponding errors.



Scheme of error corrected teleportation. The initial state $|L_5\rangle$ allows us to reconstruct the basic entangled state $|0+\rangle + |1-\rangle$ if the teleportation fails.



Real part of reconstructed density matrix for state $|0+\rangle + |1-\rangle$ with error at 2nd qubit. The fidelity is measured to be $F = 0.8522$.

CONCLUSIONS

In conclusion, an error correction scheme implemented on a photonic integrated circuit has been demonstrated to protect a single quantum logic bit with 4 physical qubits. We show the information on a logical qubit can be reconstructed with a single qubit error and achieve an average fidelity of 0.86. We also use this encoding scheme to identify the error types by measuring the expectation values of the stabilizers. Finally, we extend it to the idea of fault-tolerant one-way quantum computation by rebuilding the quantum channels for teleportation. The error correction scheme can be potentially used to reduce the error rate and pave the way for universal quantum computation.