Quantum Communication over adversarial channels

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Abstract

We aim to address fundamental limitations on quantum communication through channels compromised by an an adversary. Specifically, we investigate two fundamental challenges. Firstly, we aim to efficiently characterize the noise introduced by adversarial activities. For this, we aim to develop a task-specific minimal-measurement protocol for determining noisy channel parameters. Following this, we aim to develop a strategy for preserving properties of transmitted quantum states via the noisy channel deviating from traditional error correction techniques.

Research Area:

Quantum Algorithms, Quantum Communications, Quantum Information Theory

Objectives

We aim to address a critical challenge in quantum information security: robust communication in the presence of an eavesdropper (Eve) who performs weak measurements on a quantum channel. We consider the scenario where Alice transmits two-qubit non-maximally entangled states to Bob via Eve's controlled noisy channel. The objectives are twofold: (1) develop an efficient noise tomography protocol with minimal measurements to characterize the channel parameter p, and (2) design a novel encoding scheme using ancillary qubits to preserve entangled states ($a\,|00\rangle + b\,|11\rangle$) without traditional error-correction techniques. We aim to leverage decoherence-free subspaces and noiseless subsystems for state preservation when all qubits, including ancillaries, are subject to noise. The proposed methods is expected to have significant implications for secure quantum networks and distributed quantum computing systems.

The deliverables for project task includes the following:

- **Noise Characterization Framework**: A partial tomography protocol for efficient estimation of channel parameter p with minimal measurements, including mathematical formalism describing Eve's interaction, simulation implementation, and performance validation across the parameter range ($0 \leq p \leq 1$).
- **Quantum State Preservation System**: An ancilla-based encoding scheme that protects two-qubit entangled states ($a\,|00\rangle + b\,|11\rangle$) against the above characterized noise without traditional error correction, including decoherence-free subspace analysis, resource optimization methods, and implementation-ready protocols with state preparation circuits and decoding procedures suitable for near-term quantum devices.

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