National Aeronautics and Space Administration

Robust Neural Network Decoders for Quantum Error Correction Systems

Principal Investigator: Dariush Divsalar (332); Co-Investigators: Michael Cheng (332), Samuel Dolinar (332), Michele Pacenti (University of Arizona), Asit Kumar Pradhan (University of Arizona), Narayanan Rengaswamy (University of Arizona), Nithin Raveendran (University of Arizona), Bane Vasić (University of Arizona)

Program: FY22 SURP
Strategic Focus Area: RF and Optical Communications

Objectives: Our goal is to apply Deep Neural Networks (DNN) to find iterative decoding algorithms for quantum error correction (QEC) codes, quantum low-density parity check (QLDPC) codes can approach maximum likelihood (ML) performance while increasing throughput by at least 100%, reducing hardware complexity and power consumption by at least half, and reducing the probability of decoding error by at least two orders of magnitude compared to the best existing decoders. As opposed to classical LDPC codes, in QLDPC codes the stabilizer commutativity/symplectic inner product constraints result in unavoidable cycles in the Tanner graph. Characterization of low-weight error patterns that cause failure of iterative decoders is part of this research.

Background: Quantum error correction (QEC) comes from the marriage of quantum mechanics with the classical theory of error correcting codes. Error correction is a central concept in classical information theory, and quantum error correction is similarly foundational in quantum information theory. Both are concerned with the fundamental problem of communication, information storage, and fault-tolerant, in the presence of noise.

Approach and Results: New decoding algorithms that account for degenerate errors which has no equivalent counterpart in classical error correction. Figure 1 illustrates the benefit of a quantum system using a QLDPC code compared to the same system using uncoded qubits. Deep Neural Networks (DNNs) can be used to efficiently learn 3-bit decoders with better error performance and faster convergence. We identified most relevant trapping sets in a Tanner graph of an LDPC code. Figure 2 shows a symmetric stabilizer trapping sets the red nodes represent the actual errors, and blue nodes are equally likely candidates to be declared as errors, the squares denote parity checks. We proposed a protocol for three parties (A, B and C), with a block diagram in Figure 3, to distill multi-qubit Greenberger-Horne-Zeilinger states among the nodes of a network using quantum error correcting codes.

Significance/Benefits to JPL and NASA: Quantum communications is an area directly called out in JPL’s strategic implementation plan. This task will develop high-performance, low-complexity, fault-tolerant decoding algorithms for quantum communications systems, thus enhancing JPL’s capabilities to support future communications systems based on quantum technologies, such as secure satellite communications. A near-term example is a joint effort by NASA/NIST/NRO to develop technologies for a national quantum communications and networking strategy and mission, currently being evaluated for inclusion as a mandated 6-year quantum space program within NASA. Another example is “NASA SCaN Quantum Communications Technologies (SIP)".

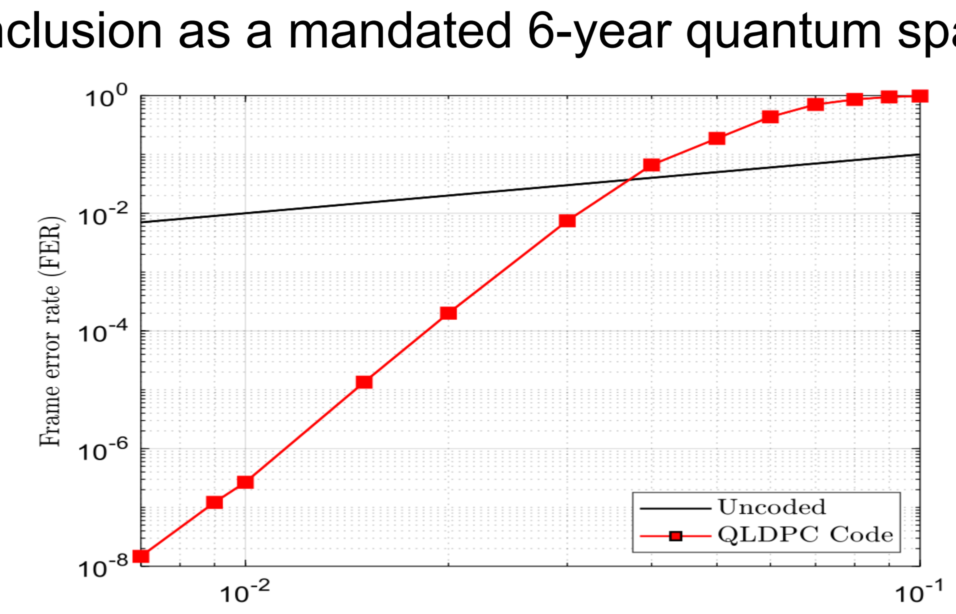

Figure 1. benefits of QLDPC codes over an uncoded qubit system for a range of physical error rates of a depolarizing channel.

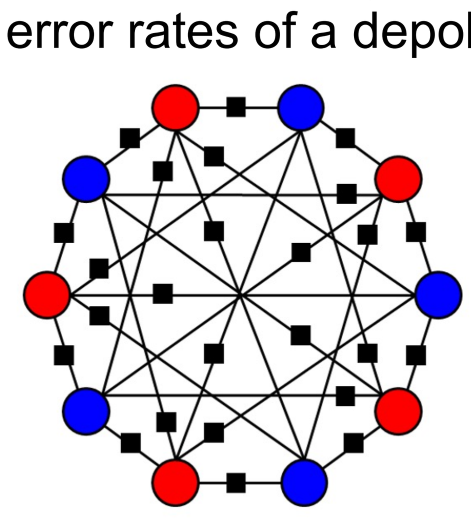

Figure 2. A specific symmetric stabilizer is present in the [[254,28]] code with circulant size of 127

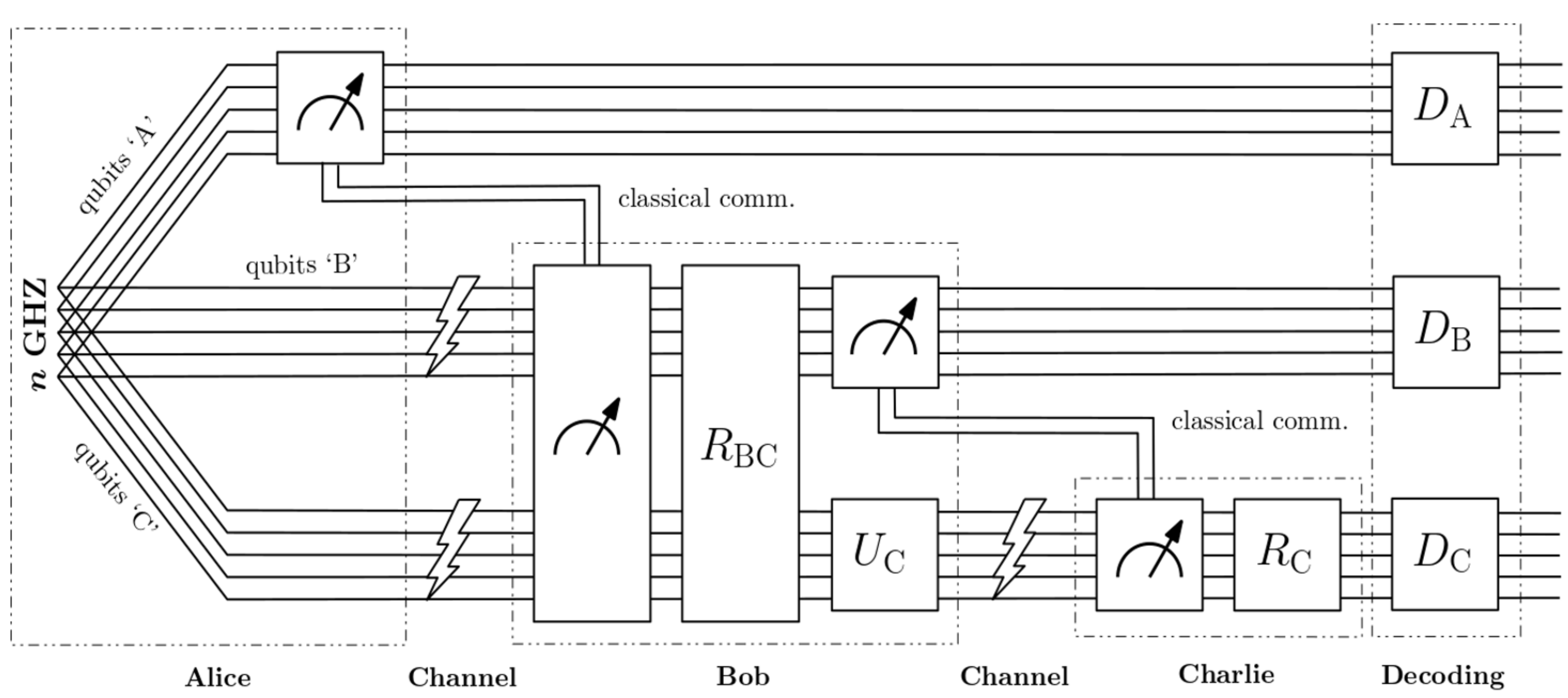

Figure 3. A protocol for distilling Greenberger-Horne-Zeilinger states using stabilizer codes

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

Clearance Number: CL#
Poster Number: 53 (RPC#SP22013)

Publications:

A. Narayanan Rengaswamy, Nithin Raveendran, Bane Vasić, Dariush. Divsalar, Michael Cheng, and Sam Dolinar, “Tutorial on quantum error correction and recent developments in quantum LDPC codes,” in Information Theory and Applications Workshop (ITA 2022), San Diego, California, May 2022.

B. Twelve more publications by University of Arizona co-investigators during FY 2022 on quantum error correction (QEC) including neural network decoders for QEC codes. The list is included in the Final report.

PI/Task Mgr. Contact Information:

Email: Dariush.Divsalar@jpl.nasa.gov