Summary of : Realization of Deterministic Quantum Teleportation with Solid State Qubits

Alex Hahn May 19, 2014

Introduction

As quantum computational machines come to fruition there develops a need to analyse, apply, and take advantage of the peculiar behavior of quantum mechanics. One way, which we discussed somewhat at the end of our course, is communication via entangled states, otherwise known as quantum teleportation. I've chosen to write about this paper from the Physics Department in Zurich Switzerland* (see citation at end) because it has a more graspable and relatable presentation relative to our class when compared to the more physics based ("what happens to the Hamiltonian", "Ising model", etc) presentations of other papers. However there are still many sections that go slightly above my head / beyond the scope of the course which I will also briefly point out.

The paper starts off with an abstract on the relation between a need to transfer information in the classical sense and a claim about its realization in the quantum communication and information processing world. The paper claims to detail a "superconducting" quantum circuit capable of the teleportation of the state of a qubit to a distant observer ("macroscopic"). This would be an important result in making "repeaters" for quantum communication.

The paper is not overly cavalier and points out despite promises of advancement in information science, logic gate circuitry, construction of entangled states, algorithmic speed up, and error correction, the physical engineering of networks and "connecting topology" on actual chips is a central problem.

Implementation, Protocol, and Teleportation

The paper then moves onto an explanation of superconducting circuit architecture and its exploitation which I will leave out because a) I don't understand it fully and b) it is way out of the scope of the class. The punchline seems to be qubit-qubit coupling on the hardware ("accross horizontal and vertical resonators").

The physical experiment's design is to (at some high rate) quantum teleport over a macroscopic distance of 6 mm between to quantum systems. An important coursework related point is then made that the experiment succeed with "order unit probability" for any input state due to the fact that they can prepare maximally entangled two-qubit states and distinguish all four two-qubit states from observation via measurement.

as detailed in class, one of the four Bell states:

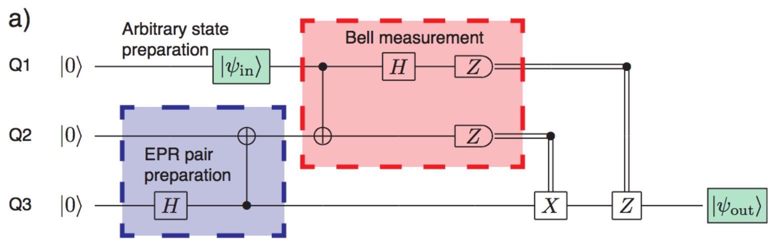
$$\left|\Phi^{\pm}\right\rangle = (|00\rangle \pm |11\rangle)/\sqrt{2} \text{ and } \left|\Phi^{\pm}\right\rangle = (|01\rangle \pm |10\rangle)/\sqrt{2}$$

At the risk of going over stuff we've explained proficiently in class, the protocol is that an unknown state $|\psi_{in}\rangle$ of qubit "Q1" which the sender has is transferred to to the receiver's qubit "Q3". To do this both parties have already prepared an entangled Bell state between another qubit Q2 and Q3. When the sender measures Q1 and Q2 the qubits in his possesion are put into one of the bell states enumerated above. More importantly the receiver's Q3 is projected into a state

$$|\phi_{out}\rangle = \{\mathbf{1}, \hat{\sigma}_x, \hat{\sigma}_z, i\hat{\sigma}_y\} |\psi_{in}\rangle$$

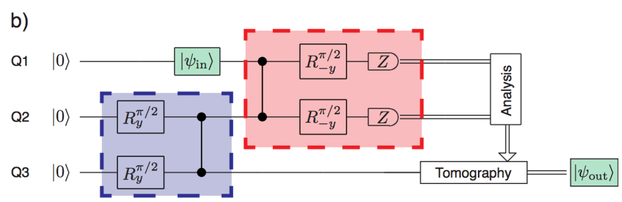
Which signifies that the he holds the input state but with a single rotation applied. Lastly the "feed forward" (?) step is performed (think opposite of "feedback" I guess).

We finally arrive at a point where we can detail and model the operations/ protocol via gates we learned about in class!



where we first prepare a Bell state of Q2 and Q3 in the blue box, the arbitrary $|\psi_{in}\rangle$ state is in green, and the measurement (of the Bell state) occurs in the red box. The H operators is our familiar Hadamard while the X and Z operators are Pauli matrices $\hat{\sigma}_x$ and $\hat{\sigma}_z$, and lastly we have our familiar CNOTE-gates.

However for the paper's implementation of the circuit, "controlled-PHASE" gates are used (vertical lines with •'s on both sides) and individual Qbit rotations $R^{\theta}_{\pm y}$ of angle θ about the $\pm y$ axis * (as detailed by the diagrams in the paper)



The paper then proceeds to detail probabilistic arguments (50 (Feynman history in our book), 66, 87%) of success then rectifies these discrepancies via "photonic continuous-variable states"(?) and a final "conditional" rotation. (Followed by some advanced discussion of ions, and traps)

Advanced section on hardware and physical set up (a fair amount of the paper is dedicated to this)

Not sure what it means but "three superconducting transmons" were used along with (coupled to) "three superconducting coplanar waveguide resonators". If your interested and a diagram would suffice I've attached one in the appendix at the end.

Results

The experiment was a success with results verifying the previous claims I've written about and is summarized neatly in this graphic:

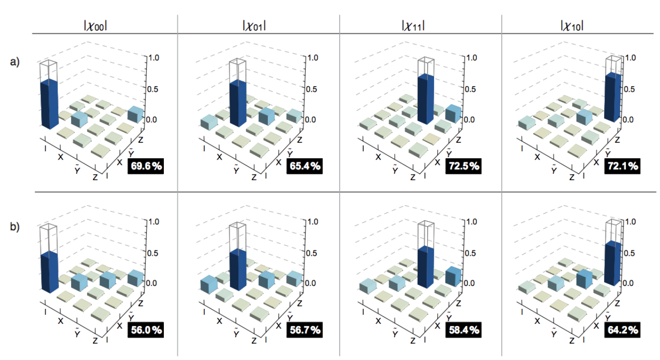


FIG. 3. Absolute values of the experimentally extracted process matrices $|\chi|$ describing the state transfer from Q1 to Q3 for the two different measurement schemes: a) Post-selected on one of the measurement outcomes 00, 01, 10, 11 using phase sensitive detection, b) simultaneous detection of all four measurement outcomes using phase preserving detection. The process fidelities are indicated in the black boxes.

Source

L.Steffen, A.Fedorov, M.Oppliger, Y.Salathe, P. Kurpiers, M. Baur, G. Puebla-Hellmann, C. Eichler, and A. Wallraff.“ Realization of Deterministic Quantum Teleportation with Solid State Qubits”. *Department of Physics, ETH Zurich*, Switzerland Feb 25, 2013

`http://arxiv.org/pdf/1302.5621v1.pdf`

Implementation of hardware: