$\mathbf{QNC}_1 \subset$ noisy-**BQP**

Michael Benor David Ponarovsky

September 15, 2024

1 Notations.

C_g - good qLDPC, C_{ft} - concatenation code (ft stands for fault tolerance). For a code C_y we use Φ_y, E_y, D_y to denote the channel maps circuits into the circuits compute in the code space, the encoder, and the decoder. We use Φ_U to denote the 'Bell'-state storing the gate U.

2 The Noise Model

3 Fault Tolerance (With Resets gates) at Linear Depth.

Claim 3.1. *There is $p_{th} \in (0,1)$ such that if $p < p_{th}$ then any quantum circuit C with depth D and width W can be computed by p-noisy, resets allowed, circuit C', with a depth at most* $\max\{D, \log(WD)\}$.

3.1 Initializing Magic for Teleportation gates and encodes ancillaries.

The Protocol:

1. Initializing zeros. Divide the qubits into $|B|$-size blocks. Encodes each block in C_g via $D_{ft}\Phi_{ft}[E_g]\left|0^{|B|}\right\rangle$.
2. Initializing Magic for Teleportation gates encoded in C_g via $D_{ft}\Phi_{ft}[E_g]\left|\Phi_U\right\rangle$ for each gate U in the original circit .
3. Each gate is replaced by gate teleportation.
4. At any time tick, any block runs a single round of error reduction.

Claim 3.2. *Assume that an error $|e| = \gamma n$, i.e e is supported on less than γn bits, then a single correction round reduce e into an error e' such $|e'| < \nu |e|$.*

Claim 3.3. *The gate $D_{ft}\Phi_{ft}[E_g]$ initializes states encoded in C_g subject to p-noise channel.*

Claim 3.4. *With probability almost surly, the total amount of noise been absorb in a block is less than αn.*

Proof. Consider the ith block, denoted by B_i. Using the Hoeffding's inequality we have that the probability that more than $\beta|B|$ bits are flipped at time t is less than $\leq 2e^{-2|B|(\beta-p)}$. Using the union bounds over all the blocks at all the different time location we get that with probability $1 - \frac{WD}{|B|} \cdot D2e^{-2|B|(\beta-p)}$. Now using the Claim 3.2 it follows that total amount of error absorbed by a block until time t, call it X_t can be bounded by: $X_t \leq \nu \cdot (X_{t-1} + \beta|B|) \leq \nu(\gamma+\beta)|B| \leq \gamma|B|$. ☐