Effects and mitigation of realistic readout noise in Quantum Approximate Optimization Algorithm

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Abstract. We introduce a correlated measurement noise model which can be efficiently described and characterized, and which admits noise-mitigation on the level of marginal probability distributions. The model can be efficiently characterized using the Quantum Overlapping Tomography technique. We perform experiments on 11 qubits of IBM's quantum device and conclude an excellent agreement with our noise model. Finally, we study the effects of the proposed measurement noise model on the Quantum Approximate Optimization Algorithm (QAOA), including a study of what kind of covariances could appear in typical states.

Keywords: noise-mitigation; readout errors; measurement noise; QAOA

Result 1a – efficiently describable noise model
As a model for readout noise (see also recent works [1–7]), we consider a stochastic map Λ which has a structure imposed by the locality of the cross-talk interactions in the readout noise. The noise can be thought of as Λ acting on the noiseless, global probability distribution from which the measurement device samples. To fully describe the model, one needs to manipulate a number of (usually small-dimensional) matrices, the size of which depends on the amount of cross-talk in the device.

Result 1b – noise-mitigation on marginals
We show that if our noise model holds for the global distribution, then the marginal distributions are affected by a stochastic noise. This allows performing the noise-mitigation individually on the marginal distributions up to some error which depends on the level of correlations and the number of gathered samples. Crucially, our noise-mitigation procedure exhibits low sampling and computational complexity, contrary to the naive procedure performed globally .

Result 1c – efficient noise characterization
To characterize the noise matrices, we use Quantum Overlapping Tomography [8] to probe diagonal elements of the detector's POVM efficiently. To benchmark our noise model, we experimentally implement ground states of diagonal Hamiltonians and perform noise-mitigation on the level of marginals. In Fig. 1 we show results of such experiments for 30 Hamiltonians encoding random MAX-2SAT problems with clause density 4. Vertical axis represents the absolute value of the difference between true and estimated state energies, divided by the number of qubits. Red dots correspond to unmitigated results, magenta triangles to noise-mitigation based on the simple model with only pairwise correlations in the readout noise, and blue stars to noise-mitigation based on our correlated noise model. We conclude that our model performs significantly better compared to no mitigation and to the simple two-body correlations model.

Result 2 – covariances in QAOA
We show that in the task of simultaneous estimation of few-body operators that appear in QAOA [9], the covariances between them vanish for a broad class of states, lowering sampling complexity of the estimation task. The proof is based on random matrix theory, theory of random quantum circuits and information spreading in shallow quantum circuits.

Result 3 – effects of readout noise on QAOA
We study numerically and analytically to what extent readout noise can affect QAOA. We conclude that for sufficiently big (on NISQ scale) system sizes, readout noise is likely to distort both optimization and final estimation steps in QAOA. As an illustration, in Fig. 2 we present results of QAOA on 8 qubits using classical optimizer known as SPSA. We study random MAX 2SAT instances with clause density 4. Each *estimator* was calculated from 1024 samples. Vertical axis shows energy difference per qubit calculated for *expectation values* on parametrized states. Each data point is obtained as an average over 100 random Hamiltonians.

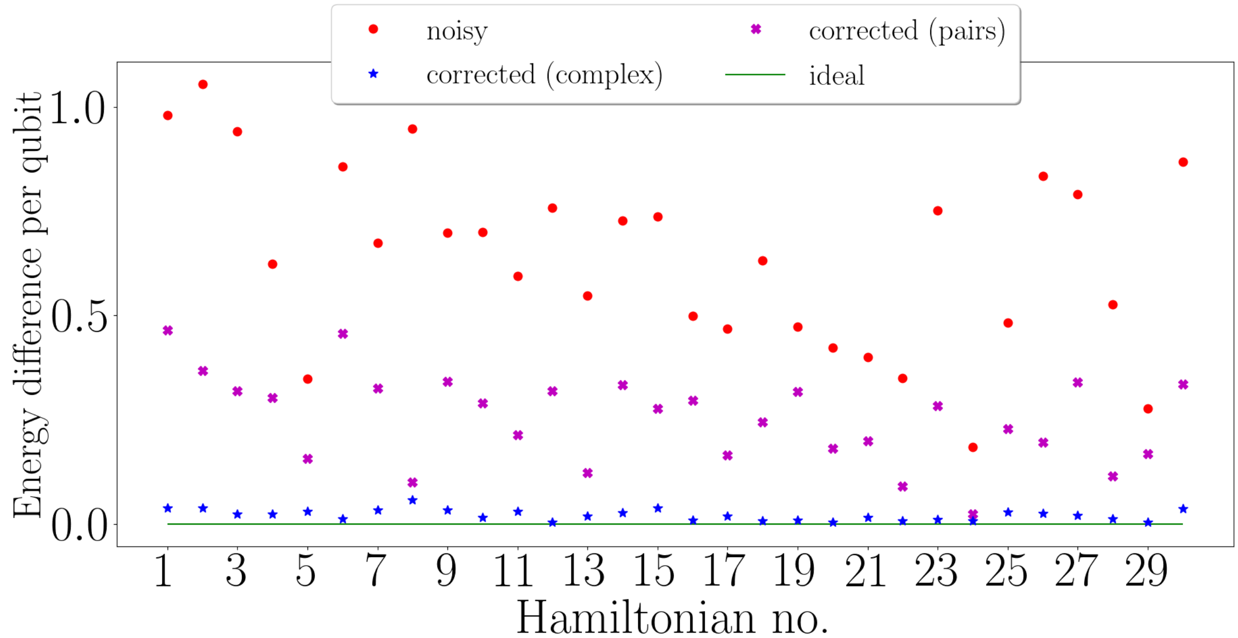

Figure 1: Noise-model benchmark for 11q experiments on IBM's Melbourne backend.

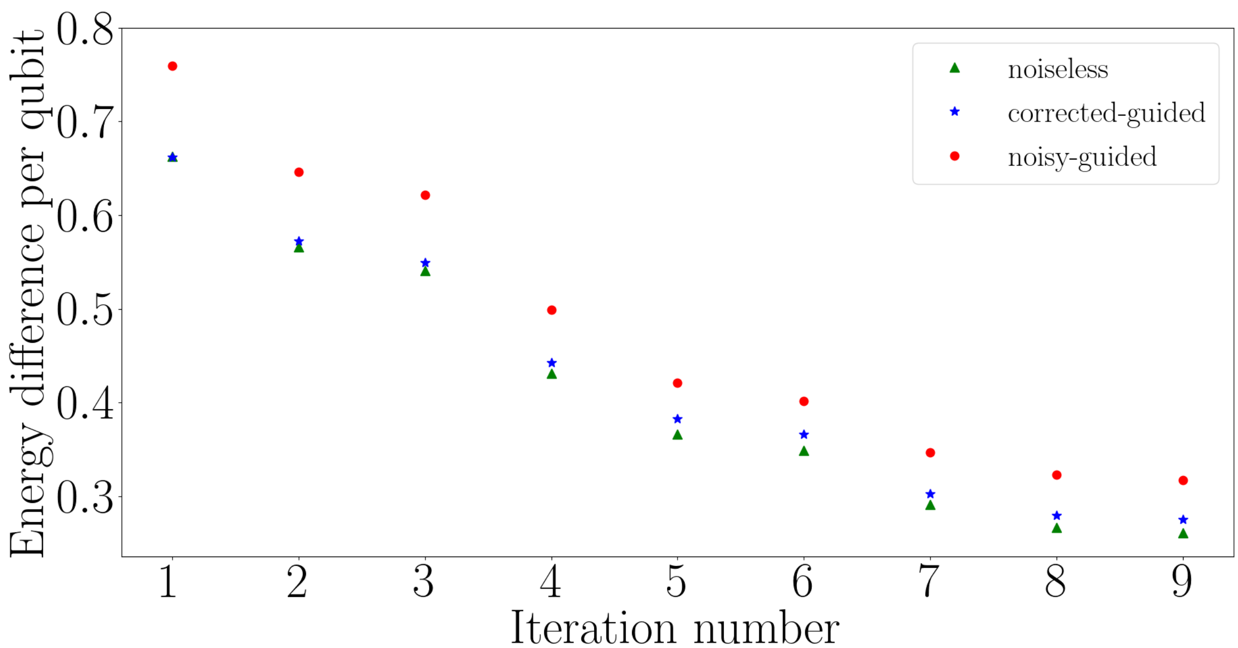

Figure 2: Numerical simulation of QAOA for 8 qubits.

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