A Overview of All Quantum Computers' Noise

In Section 6.1, we described the comparison of the noise of three quantum computers, *i.e., ibm_perth*, *ibmq_manila*, and *ibmq_lima*. In this section, we briefly introduce the overview of all available quantum computers' noise, which are the attributes of qubit readout error, qubit T1 time, qubit T2 time, and quantum gates. The time range and interval are the same as the settings in Case Study I (*i.e.,* seven days and one day, respectively).

As shown in Fig. 8 there are nine out of 24 quantum computers available on March-3-2022. Among them, Computer *ibmq_armonk* has only one qubit, Computer *ibm_lagos*, *ibm_perth*, *ibmq_jakarta* have seven qubits, and other five quantum computers have five qubits.

For the noise of qubit error rate (Fig. 8 (A)), four quantum computers have stable and high performance, such as *ibm_lagos*, *ibm_perth*, *ibmq_manila*, and *ibmq_quito*, while the qubits in other quantum computers are noisy regarding the readout error, as indicated by the number of red circles. For the noise of T1 time (Fig. 8 (B)), *ibm_perth* and *ibmq_manila* are much better than other quantum computers regarding the T1 noise, while *ibmq_belem* and *ibmq_lima* are the noisiest quantum computers on March-5-2022. The other quantum computers have a intermediate noise for T1 time. However, for another noise of decoherence time, *i.e.,* T2 time, a different noise pattern could be observed in Fig. 8 (C). *ibmq_jakarta* and *ibmq_manila* are much noisier than other quantum computers, as indicated by the number of large red circles. Thus, the user and we found that the noise pattern can be totally different for a quantum computer. Moreover, we can easily find that the queuing numbers of quantum computers vary on the day of execution. Considering the quantum algorithm to be executed, selecting an appropriate quantum computer concerning the noise type and the corresponding magnitude according to the scale of the quantum algorithm is important for the fidelity of the execution results and the cost of time. *VACSEN* integrates the above factors and informs the users of the noise and properties of all quantum computers via the proposed circuit-like design, making it more effective and time-saving for quantum computing users.

B Fidelity of the Execution Result

In Section 4.3, we introduced the dataset for driving *VACSEN*. The last step for executing a quantum algorithm is visualizing the fidelity of the execution result, which is used for validating the previous selection of quantum computers and compiled circuits. In this section, we introduce the approach for fidelity calculation.

We extract the execution results of a quantum algorithm from the remote quantum computing platform and further calculate the fidelity in the processing module. Followed by the methodology proposed by prior work [15, 39, 55], we use Hellinger distance [30] for the fidelity calculation.

$$Fidelity = (1 - H^2)^2, \tag{4}$$

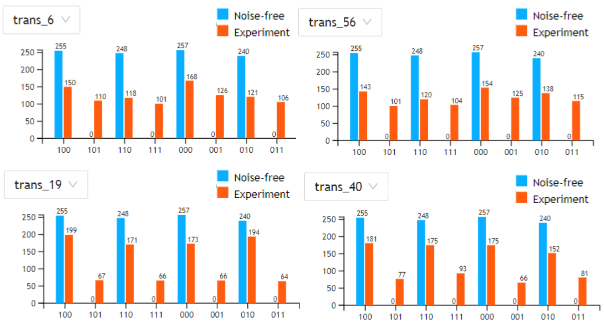
where H is the Hellinger distance [30]. For two probabilities distributions $P = (p_1, ..., p_k)$ and $Q = (q_1, ..., q_k)$, their Hellinger distance is defined as:

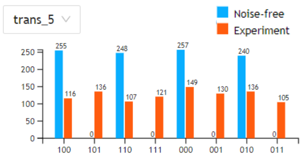
$$H(P,Q) = \frac{1}{\sqrt{2}}\sqrt{\sum_{i=1}^{k}(\sqrt{p_i} - \sqrt{q_i})^2}. \tag{5}$$

C Post-execution Analysis

In Section 5, we explained the Probability Distribution view, which is for the execution result display. Through our interview with five experts in quantum computing, they suggested that it is crucial for quantum computing users to get the execution result from *VACSEN*. Given that the execution result is the probability distribution for all possible states (e.g., 00, 01, 10, 11 for a 2-qubit quantum circuit)., the total number for all states is determined by the shot number (e.g., 1000 in Case Study I and Case Study II). As shown in Fig. 9, the grouped bar charts visualize the state distribution of the result, where the blue bars denote the ideal noise-free result generated by the Simulator "*AerSimulator*", and the red bars represent the actual experiment results with noise.

Fig. 8: Noise awareness for all quantum computers in the IBM Q quantum computing platform. The calibration data was profiled on March-3-2022. The account is under "IBM Quantum Research" hub.





Compiled Circuit	*Fidelity (%)*
trans_6	*55.5%*
trans_56	*55.4%*
trans_19	*73.9%*
trans_40	*68.3%*
trans_5	*50.6%*

Fig. 9: Probability Distribution views and the corresponding fidelity.

As shown in Fig. 9, the five Probability Distribution views were the results of the five compiled circuits selected for the in-depth comparison Case Study II. The blue bars represent the ideal state distribution for the given *Shor-15-Qiskit* algorithm, which has four theoretical states in the noise-free condition (*i.e., 100*, *110*, *000*, *010*). However, the actual result has eight states as some qubits had an erroneous flip, one of the noise sources. Thus, some qubits generated a bias compared to the ideal state, leading to an extra state except for the three noise-free results.

From the table in Fig. 9, Circuit *trans_19* generated the best result with the highest fidelity (**73.9%**), while Circuit *trans_5* was with the least fidelity (**50.6%**). The fidelity difference between the two compiled circuits is over 20% in this case, which is rather large and can not be ignored. Meanwhile, we can observe from the Probability Distribution view for *trans_5* that the shot number of the state "101" (*i.e.,* 136 shots) was larger than the number of the theoretical states "*100*" and "*110*" (*i.e.,* 116 and 107 shots, respectively). The large erroneous state numbers will result in an incorrect execution as the actual execution in a real quantum computer is performed without a simulator providing an ideal result. The same noisy patterns can also be found in Circuit *trans_6* and *trans_56*. Thus, the above cases make it more important to be aware of noise in the compiled circuits and avoid the noisy circuits before the execution, which is one of the major advantages of *VACSEN*.