Comment on IEEE Metrics

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Please find below IBM's comments on the document "An IEEE Framework for Metrics and Benchmarks of Quantum Computing". Given our area of focus, we will only comment on metrics for circuit based quantum computers. First we will give some general comments and then we will give some proposed metrics/benchmarks.

Our first comment is on the difference between metrics and benchmarks. In most cases, the definition of the metric is inclusive of the method by which the metric is measured and so there is really no reason to differentiate metric and benchmark. Perhaps a broader sense of the term benchmark is the entire process of obtaining the metrics (i.e. "to benchmark a device"). We see no reason to split out metrics and benchmarks.

Second, we see no reason to define manufacturing and packaging technology layers as there are few metrics for these layers and what metrics do exist will likely be confidential. If there are major deficiencies in the manufacturing and packaging these will show up in the qubit metrics.

In general, although the proposed breakout of technology layers is good in terms of a system integration overview, it does not make sense for metrics. All metrics are dependent on multiple technology layers. Even something as simple as a T1 measurement requires proper manufacturing, packaging, a physical device and a classical control/measurement system. Instead of considering technology layers we would instead classify metrics in terms of the elements of a typical quantum experiment (qubits -> gates/measurements -> circuits/algorithms -> experiments). Here each of these metrics can apply to either physical or logical qubits, so we don't feel it necessary to compile a separate list of metrics for logical qubits. There is a set of metrics (lumped with gates and measurements) which is not really covered in the original framework which are feedback metrics. These are tremendously important given the goal of fault-tolerance.

A final comment on metrics is that they will be naturally changing in time for any given system. How they change in time could be an important part of any system benchmark. In particular, there needs to be consensus on how time varying parameters are presented to the community (average, maximum, minimum?). If one team is giving the maximum and one the average this does not present an accurate comparison of these devices.

<u>"Qubit" Metrics</u>

Metric	Experiment	Significance
T1 (Q=w*T1)	Excite the qubit and measure the exponential decay time back to the ground state.	The T1 time (more implementation independent the qubit Q) sets a natural upper bound on the number of operations that can be performed by a qubit (absent error correction)
T2 (Q_phi=w*T2)	Hahn echo	Indicates the level of phase noise in the system, also sets a bound on the number of operations.
Qubit Temperature	After waiting 10's of T1 times what is the	Indicates the thermalization error and without active reset the initialization error.

	population in the qubit excited state.	

"Gate/Measurement" Metrics

Metric	Experiment	Significance
Gate Fidelity	Randomized benchmarking, Simultaneous randomized benchmarking	The error per gate, which indicates the level of algorithmic error to expect also important for determining error correction thresholds.
Readout Fidelity	Prepare the excited state and measure the state, prepare the ground state and measure the state	Assuming these states can be prepared with higher fidelity than the readout, this is a measure of error in the outcome of an experiment
Feedback round trip time	Start of a measurement to the end of a conditionally applied gate	Important for error correction, should be normalized to the typical timescales.
Feedback reset fidelity	Prepare a qubit in a random state, measure and conditionally rotate back to the ground state. Measure the ground state population	Proxy for the fidelity of a simple feedback circuit as is needed for fault tolerance.
Teleported CNOT fidelity		

"Circuit" Metrics

Metric	Experiment	Significance
N-qubit Clifford Fidelity	Randomized Bechnmarking	Proxy for algorithmic fidelity
Quantum Volume	arXiv:1811.12926	Computationally useful size of the system.
State Fidelity of Graph State		Amount of entanglement present in the system.

"Experiment" Metrics

Metric	Experiment	Significance
Repetition Rate	How long does the system wait between circuits	Sets the data output of the device
System Load Time	How long does the system take to load a 10 qubit experiment of 100 circuits with 100 random gates per qubit	Sets the data output of the device