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Cloud Quantum Computing Concept and Development: A Systematic Literature Review

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Abstract

A cloud quantum computer is a quantum computer that can be accessed in a cloud environment through a network. Today, there are numbers of cloud quantum computing services that can be accessed by users. They are used to solve complex problems that require powerful computing. Different cloud quantum computing services deliver different architecture and performances. In our study, we conducted a research on some services to test and evaluate the performances of different cloud quantum computing services and make a comparison out of it. The test will be conducted using two different methods such as *visual programming* and *qiskit*. From the result, we can see that the amount of qubit per backend and shots per run pretty much affect the execution time of a cloud quantum computing. This test will give the users some insight and enables them to decide which cloud quantum computing services deliver better performance or faster execution time based on the specification each cloud quantum computer offers.

Keywords: Cloud, Quantum Computing; Benchmarking; Comparison

1. Introduction

Huge companies nowadays like IBM, Google, Microsoft and Amazon are on pace to develop cloud quantum computers. They combine quantum computers with cloud computing that can be accessed by a network without having

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the physical quantum computer[1]. It means soon enough, people as a basic user will have the opportunity to test the power of quantum computers in a cloud computing environment[2].

In this paper we will be discussing cloud quantum computing and also do research to compare cloud quantum computing services around the world. In our research, we will observe the available cloud quantum computing and the result they deliver. At the end, there will be a comparison between each cloud quantum computing service based on their performances, amplitudes, times and architecture. Mainly we will be conducting the research on IBM and Qutech cloud quantum computing technology. The reason why we choose IBM's cloud quantum computing is because they have made a cloud based quantum computing platform that can be used by people, hence it will be easy for us to have a look at it and test its performance. And for IBM, they have been developing quantum computers since more than 10 years ago and it is also believed that IBM has created one of the strongest if not the strongest quantum computer with 53 qubit[3]. And for Qutech, not only do they provide cloud-based quantum computing platforms, but they also provide various hardware chips so that we can try to execute our algorithm with their Spin-2 or Starmon-5 quantum processor[4].

The rest of this paper will be as follows. In the Methodology section, it will explain the basic theory behind Cloud quantum computing such as superposition and entanglement. In the research section, the specification and the comparison between cloud quantum computing services will be shown. The result of the tests and comparison will be generally explained in the discussion section. And lastly in the conclusion section, will give a summary based on the conducted research and result with a hope that it will give some clear knowledge and insight about different kinds of cloud quantum computing services performances.

2. Methodology

We will conduct our research based on available cloud quantum computing out there, the cloud quantum computing that we choose are:

- IBM quantum cloud computing – https://www.ibm.com/quantum-computing/
- Quantum Inspire by qutech – https://www.quantum-inspire.com/

We will try a couple basic things in the cloud quantum computing such as determine the final result from the test that we conduct and will compare the failure result or error value from the result to determine its accuracy from each test.

The test we will conduct will be using two different methods using visual programming where we modified the quantum circuit by using visual programming on IBM Cloud Quantum Computing and qiskit where we modify the quantum circuit by code programming that will be demonstrated on Quantum Inspire.

The detailed step that will be conducted on the cloud quantum computing will be involving basic quantum computing theory and a quantum algorithm:

2.1. Cloud quantum computing Superposition (Hadamard Gate)

For each cloud quantum computing we will test the very basic of cloud quantum computing capabilities that is superposition a condition where a quantum computer can exist in different multiple states at once, for example the quantum computer can have a value either one or zero at the same time[5]. To do this quantum computers use what is called "QUBIT" to achieve superposition compared to classical computing which uses bits to store their value[6].

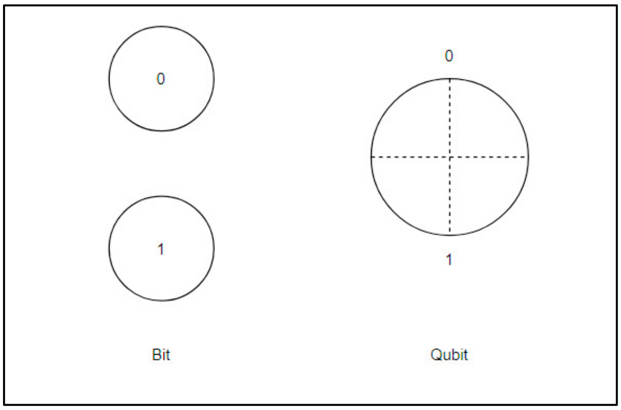

Fig. 1. Bit and Qubit illustration[6]

The state of the qubit will be zero or represented using $|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$ and the state of one will be one is represented as. $|1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$

At first the state of the qubit will always be set to $|0\rangle$ or $|1\rangle$ to achieve superposition we will use the *Hadamard Gate*, it's basically map the initial qubit state from $|0\rangle$ to $\frac{|0\rangle + |1\rangle}{\sqrt{2}}$ and from $|1\rangle$ to $\frac{|0\rangle - |1\rangle}{\sqrt{2}}$ which from that measurement will make the result of the state to equal probability of 1 or 0 (50% resulting in 1 and 50% resulting in 0) for each test that is conducted[7].

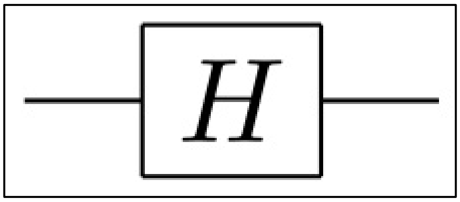

Fig. 2. Hadamard Gate illustration[7]

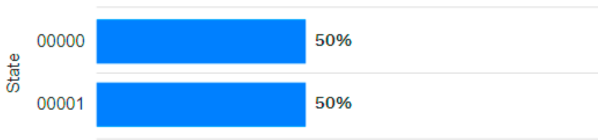

Fig. 3. The result probability illustration[8]

The zero and one from the visualization represent each qubits value as we can see the far right qubits represent the qubits value we will test.

2.2. Cloud quantum computing Entanglement (Bell State)

Quantum entanglement is a state where a state of a particle influences other particle state because changes happen in the original particle, this is also how each particle can communicate through entanglement[9]. This state can also be achieved through what's called a bell state where one qubit can influence other qubit's value[10].

To create a bell state we need a control qubit and a target qubit, the control qubit will determine if the target qubit will change its state, to achieve this we will use the *CNOT gate*[11].

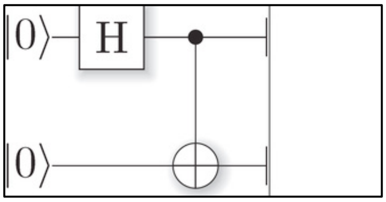

Fig. 4. Bell state illustration[11]

The CNOT gate will act as follows, if the state of the control qubit is |0⟩ then the target qubit state will remain as its initial state, but if the control qubit state is |1⟩ then the result will change the target value from |0⟩ to |1⟩ or from |1⟩ to |0⟩. So the result of the Bell state will likely be 50% |00⟩ and 50% |11⟩[12].

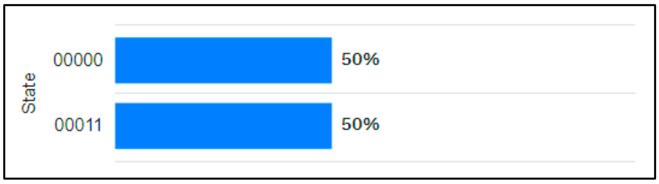

Fig. 5. Bell state result probability illustration[12]

3. Result

Before we take a look at each cloud quantum computer performance, we must take a look at the basic specification each cloud quantum computer has to offer.

Table 1. Basic quantum service comparison

An example of a column heading	Cloud Quantum Computing	
	Column A (*t*)	Column B (*t*)
Visual Programming	v	-
Qiskit	v	v
Max. Qubits per Backend	5 - 32	5 - 26 (Basic Acc) & 5 - 31(Advance Acc.)
Currently Available Backend	10 (for Developer)	3 (for Basic Acc)
Available Shots per Run	1, 1024, 4096, 8192	Max 4096

On the quantum service comparison table, we listed all basic services that each cloud quantum computing can deliver, the point of the table here is just to represent the currently available cloud quantum computing, the table is not representing whether one cloud quantum computing is better than the other one just because the cloud quantum computing has more features.

3.1. Cloud quantum computing Superposition

First to imply superposition, we will put Hadamard gate on the qubit we will test. On this test we will use visual programming that IBM currently have and Qiskit on Quantum Inspire.

```
OPENQASM 2.0;
include "qelib1.inc";

qreg q[5];
creg c[5];

h q[0];
measure q[0] -> c[0];
```

Fig. 6. IBM's Qiskit for superposition

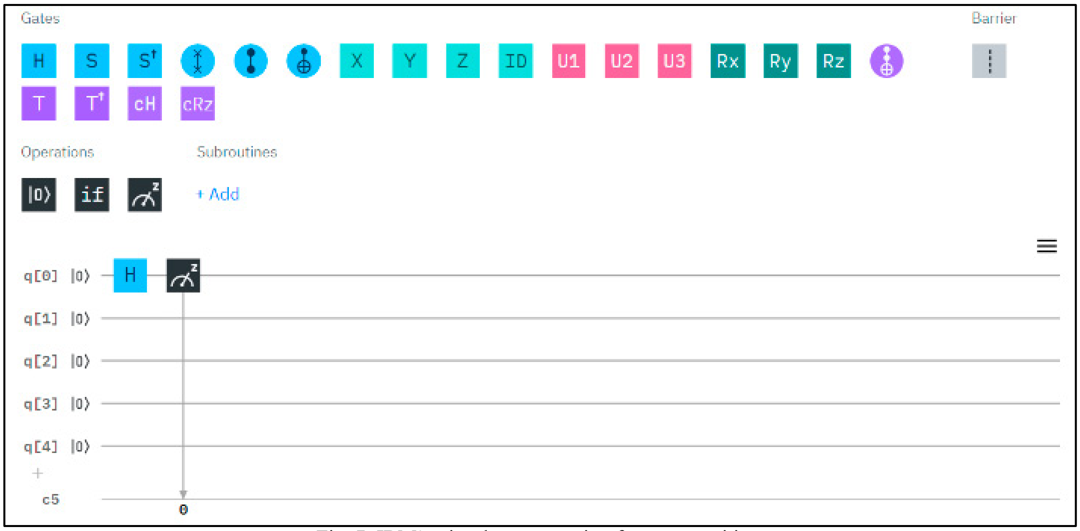

Fig. 7. IBM's visual programming for superposition

```
version 1.0

qubits 5

# start writing your code here
H q[0] #execute Hadamard gate on qubit 0
measure q[0]
```

Fig. 8. Quantum Inspire's Qiskit for superposition

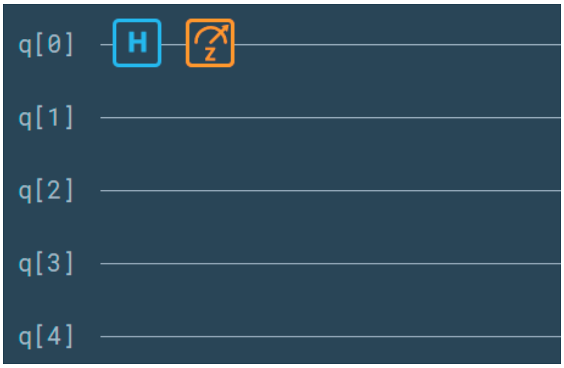

Fig. 9. Quantum Inspire's quantum circuit visualization for superposition

As mentioned before the IBM cloud quantum computing can do visual programming (moving quantum circuit component) and as well Qiskit (changing quantum circuit through code programming), the quantum inspire can do qiskit but can't do visual programming the above image is just how quantum inspire visualize the quantum circuit but can't do visual programming on it.

For each we will execute exactly 4096 shots to get more accurate data, for this specific test we will run it on IBM's ibmq_burlington server and Quantum Inspire's QX single-node simulator backend.

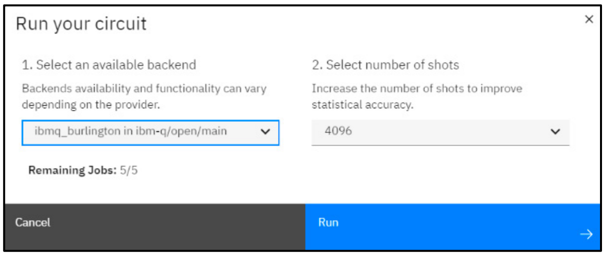

Fig. 10. IBM cloud quantum running test for superposition

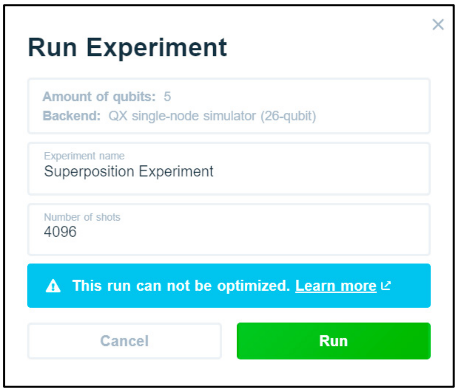

Fig. 11. Quantum Inspire running test[13]

Here are the table of comparison from each cloud quantum computing on superposition.

Table 2. Cloud quantum computing superposition table of comparison

Cloud quantum computing	Shots	Execution time	Off-value percentage
IBM's ibmq_burlington server	4096	23.9s	0.5%
Quantum Inspire's QX single-node simulator	4096	83.2s	0.1%

Fig. 12. IBM's test result for superposition

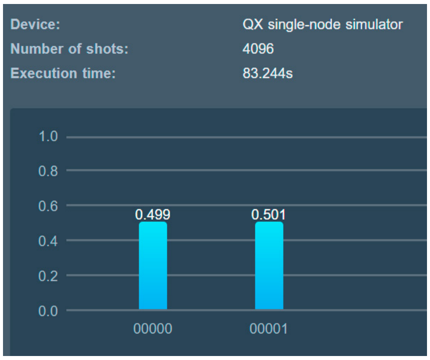

Fig. 13. Quantum Inspire's test result for superposition

3.2. Cloud quantum computing Entanglement (Bell State)

To create entanglement or bell state in our cloud computing we will need to use the hadamard gate again to create probability of different results when the control gate has a different value from the initial state and resulting |00⟩.

```
OPENQASM 2.0;
include "qelib1.inc";

qreg q[5];
creg c[5];

h q[0];
cx q[0],q[1];
measure q[0] -> c[0];
measure q[1] -> c[1];
```

Fig. 14. Quantum Inspire's test result for superposition

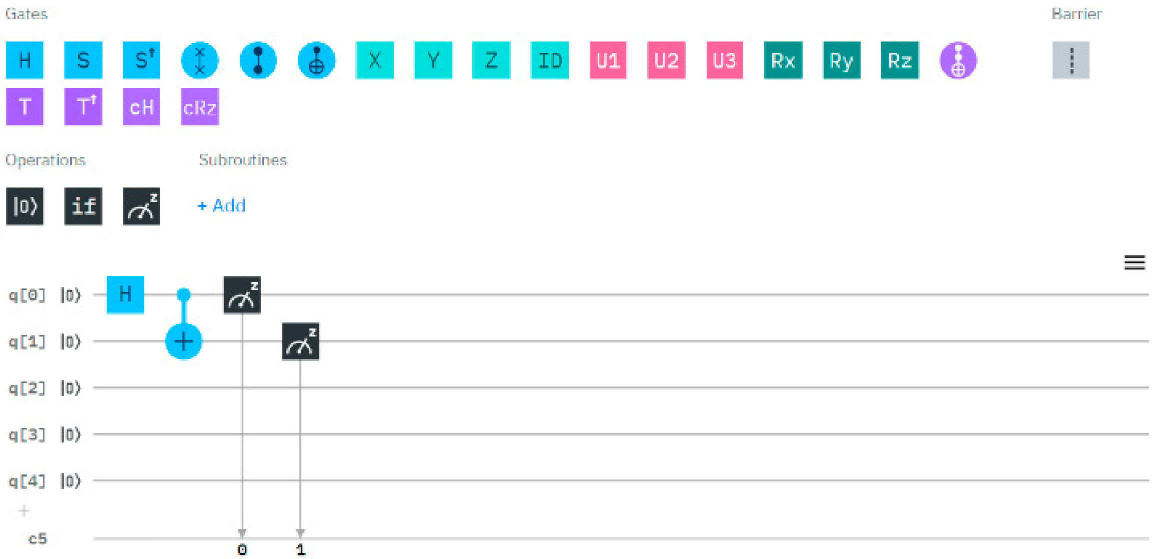

Fig. 15. IBM's Visual Programming for bell state

```
version 1.0

qubits 5

# start writing your code here
h q[0]
CNOT q[0],q[1] # CNOT gate between qubits 0 and 1
measure q[0]
measure q[1]
```

Fig. 16. Quantum Inspire's Qiskit for bell state

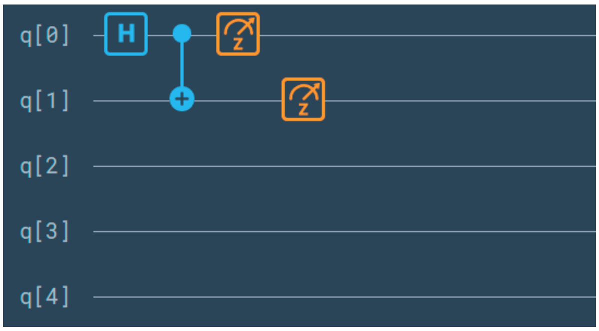

Figure 17. Quantum Inspire's quantum circuit visualization for bell state

For each we will execute exactly 4096 shots just like before and will run it on IBM's ibmq_burlington server and Quantum Inspire's QX single-node simulator backend. Here is the table of comparison from each cloud quantum computing on bell state.

Table 3. Cloud quantum computing bell state table of comparison

Cloud quantum computing	Shots	Execution time	Off-value percentage
IBM's ibmq_burlington server	4096	21.1s	17.7%
Quantum Inspire's QX single-node simulator backend	4096	83.5s	0.1%

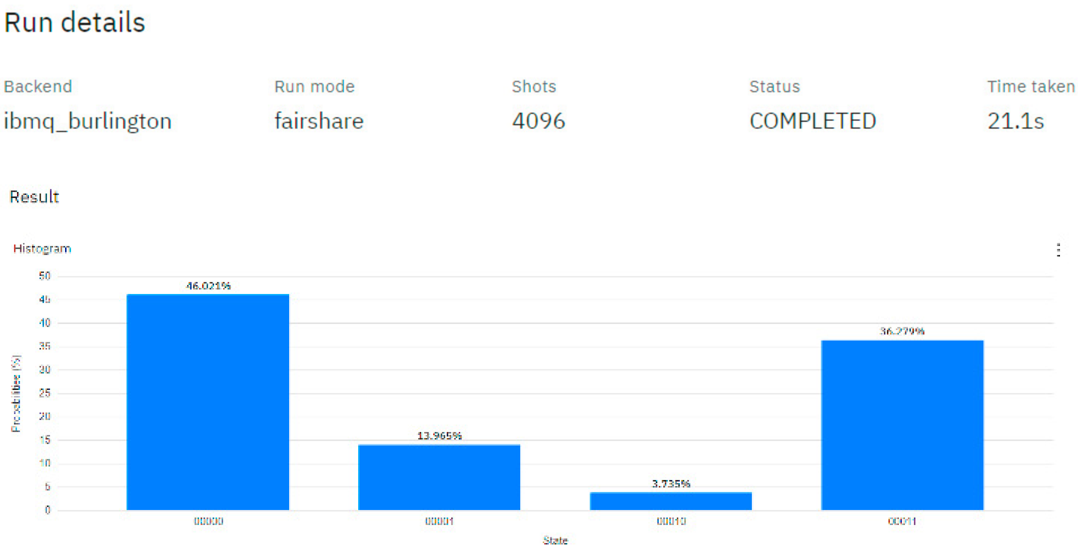

Figure 18. IBM's test result for bell state

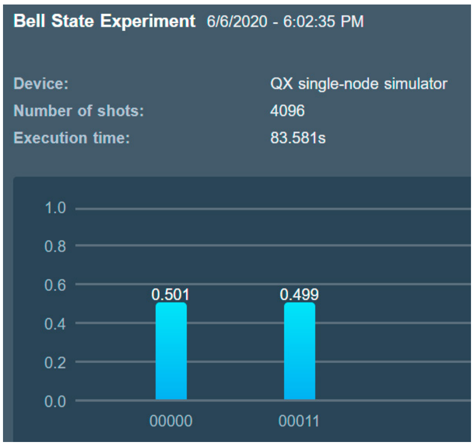

Figure 19. Quantum Inspire's test result for bell state

4. Discussion

From the result above, we can see the difference of both tests on two different quantum computers that was provided by IBM and Qutech[13]. On both tests that were done, IBM's quantum computer always finished first by large margin, compared to Qutech's quantum computer (23.9 seconds and 83.2 seconds respectively in the superposition test and 21.1 seconds and 83.5 seconds respectively in the bell state test).

On the other hand, IBM provides tools for a beginner to learn and use the quantum computer using the visual programming tool that converts the codes into interactable nodes and still provide the user the code that they make using the visual programming[14]. While Qutech's quantum computer only provides the user the tool to write the code for the quantum computer[15].

The options provided for the quantum computers also differ between providers. IBM's quantum computer lets the user use 10 different backend options (developer only), 5 to 32 qubits per backend and lets the user do up to 8192 shots per run. While Qutech's quantum computer only provides users with 3 different backends, 5 to 26 qubits for basic account, and up to 4096 shots per run.

5. Conclussion

With the technology growing rapidly at a high acceleration rate, huge companies nowadays like IBM, Google, Microsoft and Amazon are on pace to develop cloud quantum computers. They combine quantum computers with cloud computing that can be accessed by a network without having the physical quantum computer. It means soon enough, people as a basic user will have the opportunity to taste the power of quantum computers in a cloud computing environment. Making the quantum computing experience available to a lot more people more than before.

But, with the advancement of technology and invention of new technology, many people will be unable to use those technologies due to the difficulty in the learning curve, and will affect the learning rate of people in learning quantum computing, making it rather problematic for the newcomers in cloud computing.

By the result we get on the previous tests, we can conclude that the quantum computer that was provided by IBM is more beginner friendly and opens more options and learning strategies for the users, while giving a better processing time compared to Qutech's quantum computer.

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