Quantum Cloud Computing

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# Executive Summary

Quantum Cloud Computing combines the power of quantum computing with the accessibility and scalability of cloud computing. By going through the cloud, it allows users to gain access to quantum resources and run quantum algorithms without the need for specialized hardware.[1]

Quantum computing holds immense potential in advancements in the future. This will be able create many impacts and breakthroughs in various industries. Cloud-based quantum computing is able to facilitate collaborations among researchers, developers etc…. Quantum cloud computing can provide Accessibility, Scalability, Flexibility, and collaborations.

# Introduction

This report will explore the emerging paradigm of Quantum Cloud Computing, focusing specifically on how quantum computing technologies are being integrated into the cloud and how both together can create outstanding changes to different industries.

## What are the advantages of QCC?

There are many advantages to Quantum Cloud Computing (QCC) here are a few to get a good understanding where QCC can change the future [2]:

1. Cost Efficiency: Due to the fact that Quantum computing is being integrated with cloud computing this means that there is no need for expensive Quantum Hardware. Building and maintaining quantum computers requires significant infrastructure, including specialized equipment for cooling and noise isolation.
2. Scalability: Integrating with the cloud allows users to access multiple quantum processors. What does that mean? Quantum cloud Computing services provides access to a variety of quantum processors with different capabilities. Users can scale up their computational resources without worrying about physical hardware. Cloud also provides seamless upgrades.
3. Accessibility: Quantum computing in the cloud allows it to be accessible to anyone with internet connection which eliminates the need for physical proximity to a quantum computer.
4. Collaborative and Remote Work: it allows teams to collaborate remotely regardless of their location. Users can run quantum simulations and experiments on real quantum processors remotely.

## Quantum Cloud Computing Architecture

We can break down the architecture of QCC into different layers:

* Client Layer (User Interface/API)
* Users can interact with quantum cloud platforms via development kits e.g. Oiskit, Cirq
* Cloud Management Layer
* The cloud management layer manages any user requests, job queuing, and provides authentication along with simulators for debugging.
* Quantum Processing Layer
* This layer is where all the quantum computation happens, here are a few technologies that are included and will go into further depth later on in the report (Superconducting qubits, Trapped ions, Photonic qubits, quantum annealers)

# Evolution of Cloud Computing

A diagram of a cloud computing diagram

AI-generated content may be incorrect.Cloud computing allows users to access a wide range of services stored in the cloud or on the internet. Cloud computing can be traced all the way back to 1950s. Below is the different stages cloud computing went through:

1. **Mainframe Computing (1950-1970)**

Mainframes were created in 1951 they are highly powerful and reliable computing machines. Mainframes have the responsibility of handling large data such as massive input-output operations. [3]

1. **Distributed Systems (1970-1980)**

“Distributed System is a composition of multiple independent systems but all of them are depicted as a single entity to the users. The purpose of distributed systems is to share resources and also use them effectively and efficiently.” [3]

1. **Cluster Computing (1980-1990)**

Cluster Computing was created to be an alternative to mainframe computing. Each Cluster that was connected to each other by a network with high bandwidth. Cluster systems are way cheaper and more capable of high computing than mainframe systems. [3]

1. **Virtualization(1980-Present)**

Virtualization refers to the process of creating a virtual layer over the hardware which allows the user to run multiple instances simultaneously on the hardware [3]

# Ethical Concerns for Quantum Computing

1. **Resource Allocation and Inequality:**

Due to the fact Quantum Computing requires high number of resources, both physical and human. Which is only available to a few numbers of nations this can lead to an exacerbation of global socio-economic divides. [4]

1. **Misuse of Power:**

A powerful quantum computer has the ability to break current encryption schemes which can lead to breaches of privacy and security. [4]

1. **Accountability and Transparency:**

Due to the complexity within quantum algorithms this can lead to a lack of transparency and accountability. [4]

1. **Job Displacement:**

Quantum computing will have the ability to automate many jobs, which will lead to job losses. [4]

# Use Cases

## Cryptography and Data Security

Quantum Computing can play a very significant role in cryptography and data security. Quantum communication protocols such as Quantum Key Distribution (QKD) can offer theoretical security advantages based on laws of quantum physics. Quantum protocols can detect eavesdropping attempts during key exchange. Quantum communication will be able to provide more secure communication channels. [5]

## Drug Discovery and Development

“Quantum computing shows particular promise for simulating molecular interactions at a quantum level—a computationally intensive task for classical computers. As quantum hardware advances, researchers hope to more accurately model how potential drug compounds interact with biological targets, potentially identifying promising candidates more efficiently.” [5]

## Financial Modelling and Portfolio Optimization

Quantum Computing is going to cause a major shift in the financial industry. Improving financial modelling and portfolio optimization techniques. Quantum computers will be able to handle large amounts of data at the same time; by using quantum algorithms, financial institutions can optimize their investment portfolios. [5]

## Traffic Optimization and Smart Cities

“Optimizing traffic flow and supporting smart city initiatives represent a promising future application area for quantum computing. Quantum algorithms could potentially help city planners analyse complex transportation networks more efficiently than classical approaches, particularly for large-scale optimization problems with many variables and constraints.” [5]

# Limitations

## Still in Early Development

“Despite all the hype around quantum cloud computing, the technology is still in its experimental phase. Most quantum algorithms today are theoretical or in proof-of-concept stages, which means that practical quantum advantage over classical computing is still rare. Moreover, cloud-based quantum computing services often require specialized knowledge of quantum mechanics and algorithm development, making the technology challenging for non-experts.” [6] While rapid advancements are being made, it may take years before quantum cloud computing becomes a mainstream technology for commercial use.

## Quantum Hardware Limitations

“Quantum computers are still in the development phase, and there are hardware constraints that limit their practical applications. Current quantum processors have short coherence times, high error rates, and limited qubit connectivity, making complex computations unreliable. Plus, quantum systems need very specific operating conditions—such as near-absolute-zero temperatures.” [6] These limitations mean that most cloud-based quantum solutions today rely on hybrid computing models, where classical systems handle most of the workload.

# Future of Quantum Computing

“The future of quantum cloud computing is incredibly promising. As quantum technologies continue to evolve, cloud-based quantum computing is expected to play a pivotal role in sectors such as finance, healthcare, logistics, and beyond. The ability to perform complex computations more quickly and efficiently will drive innovation and new applications across these industries.” [7]

As technology evolves quantum computing is going to have a massive impact as it can bring so many benefits. We will be able to see improvements in error handling, along with quantum processors growing in qubit count and quality. In about 5-10 years we will witness quantum computer solving complex problems faster than supercomputers.

Quantum networks will be able to generate ultra-secure communication. Definitely a lot of excitement to come but with these amazing benefits will also come the downfall. Quantum error correction will become very tough to crack, building these types of computers still requires immense breakthroughs.

Quantum computing will likely become the pivotal point in computer science reshaping security and technology a whole. But we are still in the developing stage so we will be a long time away before these changes become imminent.

# Leading Platforms Offering Quantum Cloud Computing

There are some major cloud service providers that have already begun to offer QCC services:

1. AWS- they have access to multiple quantum hardware providers which enables them to offer both simulators and actual QPU access
2. Microsoft Azure Quantum – The same as AWS they have access to Quantum hardware providers but Microsoft offers Jupyter Notebook and Python SDK, they also integrate Quantum solutions with Azure cloud infrastructure.
3. IBM Quantum- I think it is afe to say there is no surprise IBM is here. They offer access to superconducting qubit-based QPUs. They have over 20 quantum systems publicly accessible, they are used as an education resource

These platforms are at the forefront of quantum computing as you see they offer different strengths with some using it for education and some integrating it into their services .

# Conclusion

Quantum Cloud Computing definitely shows promise for the future and shows pivotal advancements in computing, being able to merge unparalleled potential with the Scalability and Accessibility of cloud infrastructure. This report has outlined the benefits of QCC and the limitations it brings.

With major companies such as Microsoft and IBM the integration of quantum computing into cloud platforms is starting to go from a theoretical concept into reality. There are already different industries showing the value of QCC.

Even though QCC has all these great benefits it also comes with some limitations as it is still in the early stages including having, the skilled personnel.

In conclusion, Quantum cloud computing is definitely a pivotal point in next-generation computing as cloud and quantum computing are constantly maturing and unlocking new capabilities.

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