Journal of Online Engineering Education
ISSN: 2158-9658 Volume: 17 Issue: 1
Article Received: 12 January 2026 **Revised**: 12 March 2026 **Accepted**: 10 April 2026

Space-Based Hybrid Quantum-Classical Data Center Architecture (SBHQC-DCA) for Energy-Efficient Cloud Computing using Nature-Inspired Qubit Resource Management

Mr. S.Krishnamoorthy[1], Dr. S.Prema[2]

[1]MCA, M.Phil, SET, Assistant Professor in Computer Science Dept, KS Rangasamy College of Arts and Science, Tiruchengode, Tamil Nadu

[2]Assistant Professor and Head of the Department of Computer Applications, Arulmigu Arthanareeswara Arts and Science, Tamil Nadu

Abstract: The exponential growth of cloud computing infrastructure has led to an unprecedented surge in global data center energy consumption, currently accounting for approximately 1–2% of worldwide electricity usage. Traditional approaches to energy optimization — including virtualization, dynamic voltage/frequency scaling, and classical nature-inspired scheduling algorithms — have reached practical limits in addressing the cooling and computational power demands of modern hyperscale data centers. This research proposes a transformative paradigm: the design and theoretical validation of a Space-Based Hybrid Quantum-Classical Data Center Architecture (SBHQC-DCA), which leverages the natural cryogenic environment of deep space to drastically reduce cooling energy requirements, employs quantum error correction (QEC) software — specifically Surface Code — to mitigate quantum hardware instability, utilizes nature-inspired quantum algorithms (QIEA, QPSO, WOA) for intelligent qubit-based virtual resource management, and positions classical computers as quantum clients in a hybrid processing model.

The proposed architecture is evaluated through a multi-layered simulation framework incorporating quantum circuit simulation (via IBM Qiskit), cloud resource scheduling simulation (CloudSim Plus), and orbital thermal modeling. Preliminary theoretical analysis suggests potential energy savings of 90–95% in cooling infrastructure and up to 40% improvement in overall data center power usage effectiveness (PUE). This research addresses critical open challenges including deep-space communication latency, radiation-hardened quantum hardware design, space-based solar power integration, and quantum-classical workload partitioning. The outcome is a forward-looking, interdisciplinary blueprint for next-generation sustainable quantum cloud infrastructure.

Keywords: Space-Based Data Center, Quantum Error Correction, Surface Code, Nature-Inspired Optimization, QIEA, QPSO, Qubit Resource Management, Hybrid Quantum-Classical Computing, Green Cloud Computing, Ultra-Low Power Architecture.

1. INTRODUCTION

1.1 Background and Motivation

Modern cloud data centers form the backbone of the global digital economy, supporting services ranging from artificial intelligence model inference to financial transaction processing. However, this critical infrastructure comes at a severe environmental cost. Data centers worldwide consumed an estimated 200–250 TWh of electricity in 2022, with cooling systems alone accounting for 30–40% of total energy usage.

Simultaneously, quantum computing has emerged as a transformative computational paradigm, offering theoretical exponential speedups for optimization, simulation, and cryptographic problems that underpin modern cloud operations. Yet quantum computers remain confined to controlled laboratory environments operating at millikelvin temperatures due to the extreme sensitivity of quantum bits (qubits) to thermal noise and decoherence.

1.2 Problem Statement

Current cloud data center architectures face three interrelated and unsolved challenges:

1. Energy Crisis: Cooling systems consume 30–40% of total data center power.

2. Quantum Deployment Barrier: Quantum computers require near-absolute-zero temperatures.

3. Resource Management Inefficiency: Classical scheduling algorithms are reaching optimization limits.

1.3 Research Vision

This research envisions a three-tier computational architecture where space-based quantum processors handle optimization and AI training workloads in a naturally cold, solar-powered environment, while ground-based classical systems act as quantum clients.

2. RESEARCH OBJECTIVES

2.1 Primary Objectives

- Design a Space-Based Hybrid Quantum-Classical Data Center Architecture (SBHQC-DCA).
- Develop nature-inspired quantum algorithms for qubit resource management.
- Implement Surface Code quantum error correction.
- Quantify energy savings through simulations.
- Establish a workload partitioning framework.

2.2 Secondary Objectives

- Analyze deep-space communication latency.
- Evaluate radiation-hardening requirements.
- Investigate space-based solar power integration.
- Compare the architecture with terrestrial data centers.

3. LITERATURE REVIEW AND RESEARCH GAP

Existing research focuses on classical energy-efficient scheduling and quantum-inspired optimization, but no integrated space-based quantum data center architecture currently exists. This research fills the gap by combining quantum error correction, space deployment, and nature-inspired qubit management.

4. PROPOSED ARCHITECTURE — SBHQC-DCA

The proposed SBHQC-DCA consists of three tiers:

- Space-Based Quantum Processing Layer
- Ground-Based Classical Client Layer
- Edge/User Access Layer

Nature-inspired algorithms such as QIEA, QPSO, and Quantum-WOA are adapted for qubit scheduling and optimization.

Journal of Online Engineering Education
ISSN: 2158-9658 Volume: 17 Issue: 1
Article Received: 12 January 2026 **Revised**: 12 March 2026 **Accepted**: 10 April 2026

5. RESEARCH METHODOLOGY

Phase 1: Theoretical Framework Development

Phase 2: Simulation Development using IBM Qiskit and CloudSim Plus

Phase 3: Experimentation and Evaluation

Phase 4: Refinement, Publications, and Thesis Submission

6. CHALLENGES AND PROPOSED SOLUTIONS

Major challenges include space radiation, communication latency, and quantum hardware maintenance. Proposed solutions involve enhanced Surface Code QEC, asynchronous workload processing, and autonomous fault detection systems.

7. EXPECTED OUTCOMES AND CONTRIBUTIONS

Expected contributions include:

- First SBHQC-DCA architecture proposal
- Novel qubit scheduling algorithms
- Space-based quantum energy model
- Hybrid workload partitioning framework

Projected improvements include:

- 90–95% cooling energy reduction
- PUE improvement to 1.02–1.05
- Significant carbon footprint reduction

8. TARGET PUBLICATION PLAN

Target venues include IEEE CLOUD, ACM SoCC, IEEE Transactions on Cloud Computing, and Journal of Cloud Computing.

9. FUTURE RESEARCH SCOPE

Future work includes:

- Quantum Internet Integration
- Multi-Orbital Quantum Data Centers
- Neuromorphic-Quantum Hybrid Scheduling
- Federated Quantum Learning
- Autonomous Quantum Maintenance

KEY REFERENCES

[1] Lilhore, U. et al. (2025). QHRMOF: A Quantum-Inspired Hybrid Multi-Objective Framework.

[2] Balicki, J. et al. (2022). Many-Objective Quantum-Inspired Particle Swarm Optimization.

[3] Fowler, A.G. et al. (2012). Surface Codes: Towards Practical Large-Scale Quantum Computation.

[4] Rostami, S. et al. (2024). Hybrid ACO-IACO for Energy-Efficient Task Scheduling.

DECLARATION

We hereby declare that this research proposal is an original work conceived independently. All referenced works have been duly cited.