Enhancing Quantum Computing Service Availability:

A Multi-Region Architecture for Service-Level Fault Tolerance

Naoyuki Masumoto, Kosuke Miyaji, Takafumi Miyanaga, Toshio Mori, Satoyuki Tsukano

Center for Quantum Information and Quantum Biology, The University of Osaka

masumoto.naoyuki.qiqb@osaka-u.ac.jp

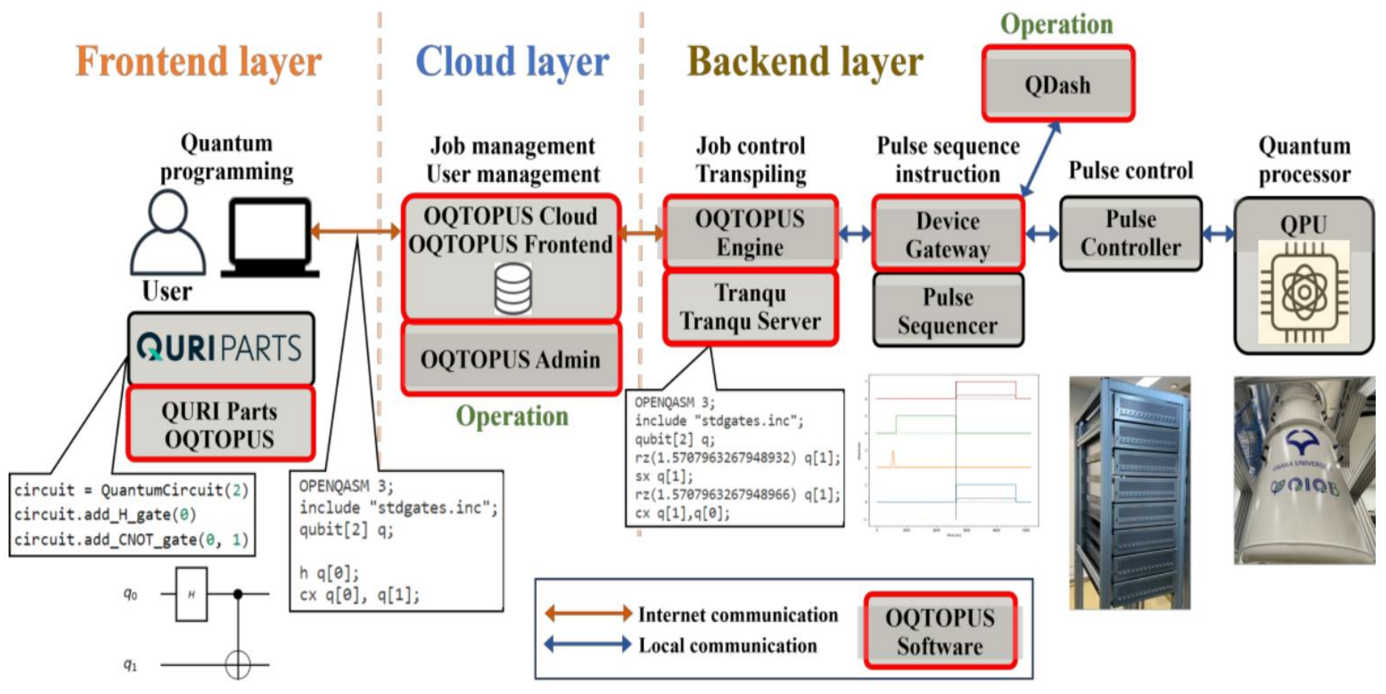
Overview

The rapid development of cloud-based quantum computing has led to the emergence of systems from providers like IBM Quantum and Amazon Braket.

While focus has centered on quantum device performance, this addresses only one aspect of system reliability. A quantum device is rendered useless if the classical infrastructure required to access it—such as APIs and networks—is unavailable. Ensuring the dependability of the entire hybrid classical-quantum system is thus a critical challenge now being recognized by the research community[1].

This poster details the construction of a cloud-based quantum system with multi-layer redundancy, which we implemented and verified in a production environment to evaluate its fault tolerance.

OQTOPUS



Three-Layer Architecture

- ✓ Frontend: Python SDK (QURI Parts OQTOPUS)
- ✓ Cloud Layer: Job/user management (AWS, OpenAPI)
- ✓ Backend: Execution, transpilation, calibration

Components

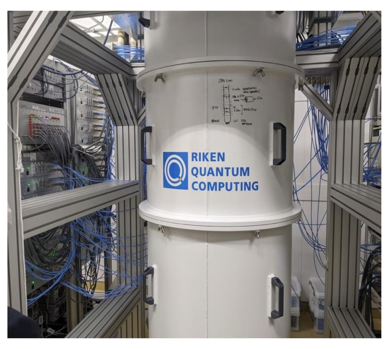
- QURI Parts: OpenQASM 3 generation and job submission
- OQTOPUS Cloud: Job control, REST API
- Engine: Hybrid execution, error mitigation, multi-programming
- Tranqu: Transpiler orchestrator (Qiskit, ouqu-tp, etc.)
- Device Gateway: Pulse-level hardware interface
- QDash: Calibration manager
- Admin UI: Operator tools

[2], [3] [4]

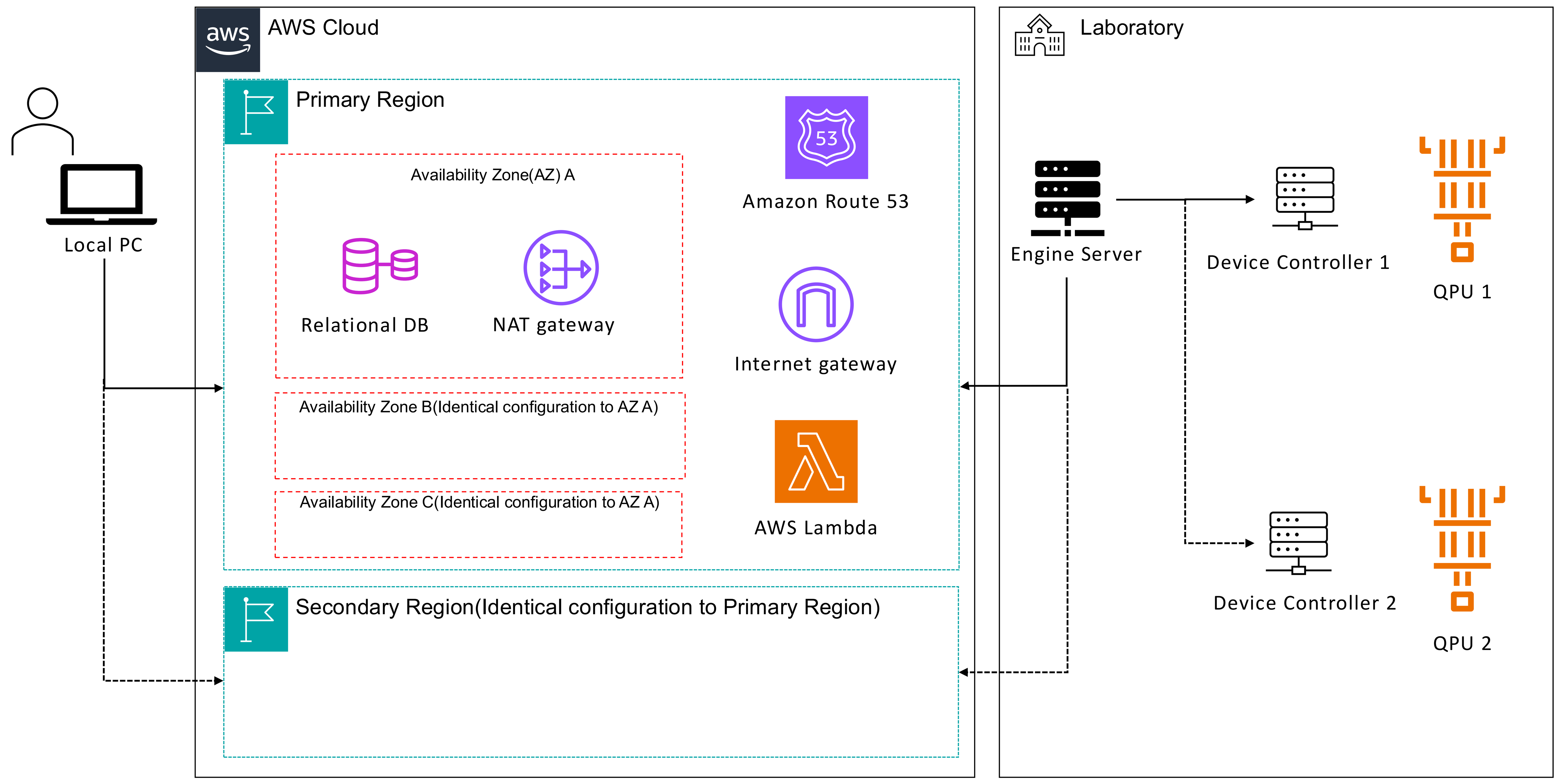
Quantum Computers Operated by OQTOPUS

From left to right

- ✓ A(RIKEN)
- ✓ anemone(The University of Osaka)
- ✓ urchin(The University of Osaka)



Methods



- **System Architecture**
  - Constructed a cloud-based quantum computing system using **OQTOPUS** (open-source system software).
  - **Full-Stack Implementation:** User Frontend -> Cloud Platform -> Backend (Physical QPUs).
- **Cloud Layer Redundancy (AWS)**
  - **Multi-AZ Deployment:**
    - Distributed infrastructure across **3 physically independent Availability Zones (AZs)**.
    - Utilized **Amazon RDS Multi-AZ** and stateless compute for localized fault tolerance.
  - **Multi-Region DR:**
    - Implemented **Active-Passive** architecture in a geographically isolated secondary region.
    - Ensures service continuity against catastrophic regional outages.
- **Backend Layer Redundancy**
  - **OQTOPUS Engine:** Manages job dispatch and QPU health monitoring.
  - **QPU Failover:**
    - Provisioned **multiple QPUs** to address hardware instability.
    - **Automated Redirection:** Traffic routes to healthy QPUs during hardware failures to minimize downtime.

Results

- **Simulation Validation**
  - **AZ Outage Response:**
    - Achieved **seamless automatic failover**.
    - **Minimal Impact:** At worst, only **1 in-flight job error** occurred during transition.
  - **Regional Outage Response:**
    - **Rapid Recovery:** Full failover to the secondary region completed in **< 1 minute**.
    - **Data Integrity:** System temporarily paused new job acceptance to ensure consistency, resuming immediately post-transition.
- **Field Deployment (Expo 2025, Osaka, Japan)**
  - **Event Success:**
    - Deployed for the **"Entangle Moment"** exhibition[5](Aug. 14-20, 2025) at Expo 2025.
    - Attracted **62,360 visitors** over a 7-day period, demonstrating high public engagement.
  - **System Reliability:**
    - **High Throughput:** Successfully processed **20,417 quantum jobs** in real-time.
    - **Proven Stability:** The purely domestic quantum cloud system maintained **100% availability** under high-volume public load, proving readiness for mass-scale adoption.

[6]

- **Media Coverage & Public Impact**
  - The successful deployment of the **"purely domestic"** quantum computer was widely covered by major news outlets, including **FNN**[7], **Nikkei**[8], **and NHK**[9].
  - Recognized as a landmark achievement in democratizing access to quantum technology through public cloud interfaces.

Conclusion

- **Service-Level Resilience is Essential**
  - Established **Service-Level Fault Tolerance (SFT)** as a critical pillar alongside qubit-level error correction.
  - Reliable classical infrastructure is the mandatory "gateway" to practical quantum utility.
- **Proven at World-Class Scale (Expo 2025)**
  - **Battle-Tested:** Flawlessly served **62,360 visitors** at the **"Entangle Moment"** exhibition.
  - **Zero Downtime:** Processed **20,417 jobs** with 100% availability, proving the architecture's stability under real-world, high-volume load.
  - Demonstrated readiness for **mission-critical** and mass-scale applications.
- **Architectural Validation**
  - Confirmed the effectiveness of **Multi-Region / Multi-AZ** redundancy against catastrophic failures via rigorous simulation.
  - Achieved **rapid recovery (< 1 min)** for regional failovers, ensuring business continuity.
- **Future Work**
  - **State Management:** Implementing cross-region data replication for stateful hybrid algorithms.
  - **Intelligent Automation:** Enhancing backend dispatch logic to further reduce operational overhead.

References

[1] Edoardo Giusto, Santiago Nuñez-Corrales, Phuong Cao, Alessandro Cilardo, Rav-ishankar K. Iyer,Weiwen Jiang, Paolo Rech, Flavio Vella, Bartolomeo Montruc-chio, Samudra Dasgupta, Travis S. Humble, et al. 2024. Dependable Classical-Quantum Computer Systems Engineering. arXiv preprint arXiv:2408.10484 (2024). arXiv:2408.10484 [quant-ph]

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[4] https://arxiv.org/abs/2507.23165

[5] https://www.qst.go.jp/site/entangle-moment/

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