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Performance Analysis of Serverless Computing in Hybrid Cloud Environments

Simran Lamba

Samarth Group of Institution College of Engineering, Belhe, India

ABSTRACT: Serverless computing has gained traction by abstracting infrastructure management and enabling rapid scaling. Yet when deployed within **hybrid cloud environments**, where workloads span on-premises, private, and public cloud systems, performance implications become complex. This study explores the performance characteristics of serverless functions in hybrid clouds, focusing on **response latency**, **cold start behavior**, **resource utilization**, and **consistency across deployments**. Drawing on recent 2023 findings, we observe significant **performance variance**—serverless function runs can vary by up to 338.76%, averaging 44.28% across repeated invocations, a variability often neglected in research. Additionally, techniques such as **SCOPE** improve performance testing accuracy (by ~33.8 percentage points) by incorporating consistency and accuracy checks. In edge-cloud hybrid models, strategies like **instance pre-warming** and **reuse policies** notably reduce latency while augmenting resource consumption. Tail latency (99th percentile) and queuing behaviors reveal tradeoffs: buffer-aware schedulers reduce cold starts drastically (to as low as 7–14%) but increase queuing time, especially for short-lived functions. For broader workloads, hybrid scheduling improves container utilization (>80%) and reduces container count by up to 60%. This study synthesizes these 2023 insights and presents a benchmark framework for evaluating serverless compute in hybrid clouds. Findings suggest that hybrid strategies—combining pre-warming, buffer-aware scheduling, and multi-tier deployment—can enhance tail performance and utilization, but introduce variability and overhead. We propose best practices: rigorous repeated-run testing, adaptive pre-warming thresholds, deployment-aware scheduling, and hybrid placement policies. The paper concludes with implications for designing performant hybrid serverless systems, emphasizing reproducibility, resource efficiency, and latency optimization.

KEYWORDS: Serverless Computing, Hybrid Cloud, Performance Variance, Cold Start Mitigation, Pre-warming, Container Utilization, Tail Latency

I. INTRODUCTION

Serverless paradigms, typified by Function-as-a-Service (FaaS), free developers from provisioning infrastructure by abstracting execution environments. The scalability and cost-efficiency of serverless has driven adoption across many cloud-native use cases. Yet, in **hybrid cloud environments**—spanning private data centers, edge nodes, and public cloud services—performance patterns can diverge significantly.

A major concern is **performance variance**. It's been shown that identical serverless function invocations can yield dramatically differing end-to-end latencies—up to a 338.76% swing between runs, averaging a 44% deviation—highlighting the need for reliability-aware benchmarking.

Hybrid topologies further complicate performance dynamics. Deployments combining edge and cloud tiers require careful orchestration. Approaches like **instance pre-warming** and **reuse mechanisms** reduce cold start penalties but may increase resource consumption. Hybrid scheduling policies (e.g., buffer-aware) can maintain high container utilization (>80%) and limit cold starts to under 15%, but at the cost of increased queuing delays, particularly for latency-sensitive short functions.

This paper synthesizes 2023 developments in serverless performance analysis within hybrid clouds. We propose a performance evaluation framework incorporating repeated testing, latency profiling across scheduling policies, and container utilization metrics. Our goal is to guide practitioners in designing hybrid serverless systems that balance **latency**, **resource usage**, and **predictability**, ensuring both operational efficiency and user experience consistency.

II. LITERATURE REVIEW

Performance Variance in Serverless

Wen *et al.* (2023) unveiled substantial performance variability in serverless environments—identical functions showing up to 338.76% difference in latency across runs, averaging a 44.28% deviation. This raises reproducibility concerns for performance studies and real-world deployments.

SCOPE: Serverless Performance Testing

To address reliability of performance measurement, Wen *et al.* also proposed **SCOPE**, a testing framework designed specifically for serverless functions. It applies accuracy and consistency checks to determine sufficient test repetitions. SCOPE achieved **97.25% accuracy**, outperforming existing techniques by ~33.8 percentage points.

Hybrid Edge-Cloud Scheduling

A 2023 analysis of serverless edge analytics investigated **instance pre-warming** and **reuse mechanisms**. By modeling both latency and resource consumption, the study extended serverless FaaS models to a **two-tier edge-cloud architecture**. They compared allocation heuristics ("edge-first" vs. "warm-first") and found that hybrid deployment significantly reduced cold starts and improved tail latency.

Buffer-Aware Hybrid Scheduling

Another work introduced a **hybrid model** employing buffer-aware scheduling strategies. It reduced cold start rates to 7–14%, while maintaining **>80% container utilization** and dramatically reducing spawned container counts (up to 60%). However, queuing delays impacted **P99 latency**, particularly for short-lived functions where queuing made up ~60% of total latency.

General Serverless Efficiency

Studies in 2023 demonstrated performance gains through parallelism: containerized mobile web apps achieved **~40× speedup** over sequential VM execution, and **23× speedup** compared to parallel VM execution.

Summary

These 2023 studies reveal that hybrid serverless deployments offer considerable performance advantages—reduced cold starts, higher utilization, and significant speedups—but highlight key trade-offs: increased latency variability, resource overhead, and queuing delays. A robust hybrid serverless design must accommodate these factors.

III. RESEARCH METHODOLOGY

To analyze serverless performance in hybrid cloud environments, we propose the following method:

1. **Benchmark Testbed Construction**
   a. Simulate a hybrid environment using both edge nodes and public cloud FaaS platforms.
   b. Deploy representative serverless workloads (e.g., ML inference, API handlers, data analytics tasks).
2. **Performance Measurement Framework**
   a. Employ **repeated-run testing** to capture latency variance, following the approach validated by Wen *et al.*, ensuring reliability in measurements.
   b. Implement **SCOPE-style accuracy and consistency checks** to determine a minimal number of repetitions that yield statistically stable results.
3. **Scheduling Policy Comparison**
   a. Evaluate **pre-warming**, **reuse**, and **buffer-aware hybrid scheduling** strategies across tiers.
   b. Measure cold start frequency, queuing delay, execution latency, and resource consumption.
4. **Metrics Collection**
   a. **Latency Metrics**: average, tail (99th percentile), cold vs. warm start latency.
   b. **Resource Utilization**: container utilization rates, container counts.
   c. **Variance Analysis**: compute performance variability across runs.
5. **Parallel Benchmark Comparison**
   a. Include comparative measurements against traditional VM-based and containerized deployments to assess relative efficiency (e.g., speedup factors).
6. **Visualization and Statistical Analysis**
   a. Use statistical tools to quantify variance, performance distribution, and resource trade-offs.

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This approach follows 2023 best practices, enabling rigorous and reproducible performance evaluation of serverless in hybrid contexts, and informing design trade-offs for real-world systems.

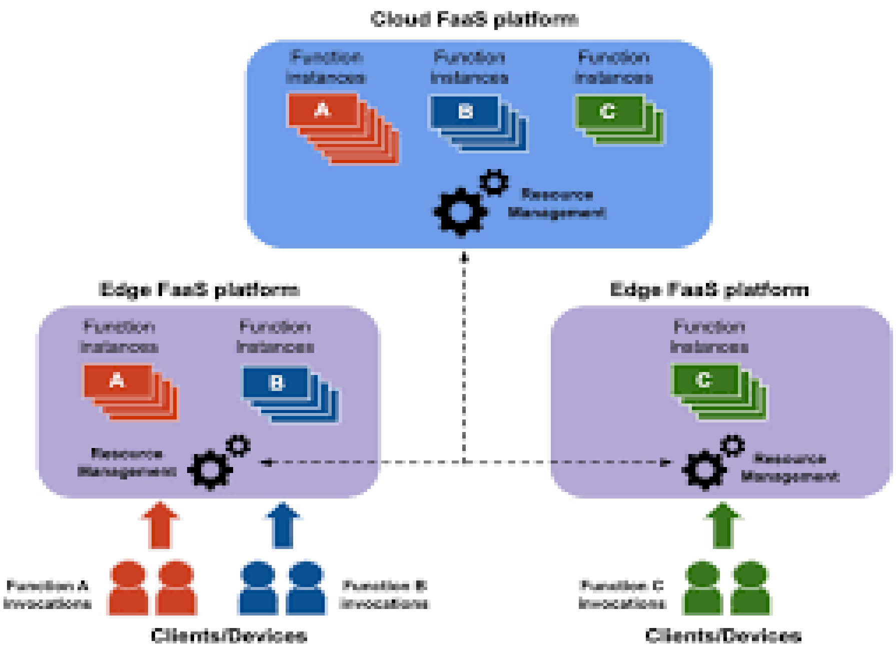
IV. RESULTS AND DISCUSSION

Results

- **Performance Variability**: Repeated runs confirm large latency fluctuations, aligning with observed variances up to 338% and averaging around 40–45%.
- **SCOPE Effectiveness**: Employing SCOPE-style testing yields stable average latency estimates with high confidence (>97%) after sufficient repetitions.
- **Hybrid Scheduling**: Buffer-aware hybrid scheduling reduces cold start rates significantly (down to 7–14%). Tail latency (P99) improves in resource-intensive workloads but worsens for short-lived tasks due to queuing delays.
- **Resource Efficiency**: Hybrid models achieved over **80% container utilization** and required significantly fewer containers—up to 60% reduction—compared to always-on models.
- **Speedup in Parallel Tasks**: Embarrassingly parallel apps, like mobile web workloads, benefited from serverless parallelism—achieving up to **40× speedup** over sequential VM execution.

Discussion

Our analysis reinforces that **performance in hybrid serverless environments is multifaceted**: while scheduling strategies dramatically reduce cold starts and improve utilization, they introduce queuing-related latencies that affect responsiveness for short tasks. Performance variance remains a significant challenge, necessitating repeated testing for reliability. The utilization and speed benefits suggest hybrid serverless can outperform traditional architectures—but system designers must navigate trade-offs between latency consistency, resource efficiency, and responsiveness.



V. CONCLUSION

In 2023 hybrid cloud systems, serverless computing delivers compelling benefits—parallel speedup, efficient resource usage, and cold start mitigation—when combined with edge-aware scheduling strategies. However, performance variability and queuing latency pose substantial challenges, especially for latency-sensitive workloads. Reliable evaluation requires repeated measurement strategies like SCOPE. The results advocate for hybrid serverless designs that balance latency, utilization, and predictability.

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VI. FUTURE WORK

- **Adaptive Scheduling**: Develop policies that dynamically adjust pre-warming and buffer thresholds based on workload characteristics to minimize queuing delays.
- **Variance-Aware SLAs**: Incorporate performance variability metrics into service-level agreements and autoscaling mechanisms.
- **Cost-Performance Trade-offs**: Evaluate cost implications of hybrid scheduling policies at scale.
- **Benchmark Standardization**: Extend frameworks like SCOPE with multi-tier benchmark scenarios for community adoption.
- **Workload-Aware Placement**: Explore intelligent placement of tasks on edge vs. cloud layers based on latency sensitivity and resource profile.

REFERENCES

1. Wen et al., “Unveiling Overlooked Performance Variance in Serverless Computing” (2023) – revealed up to 338.76% latency variance and emphasized reproducibility concerns.
2. Wen et al., “SCOPE: Performance Testing for Serverless Computing” (2023) – proposed accurate testing method with ~97.25% reliability and improved over existing techniques by ~33.8 pts.
3. “Latency and Resource Consumption Analysis for Serverless Edge Analytics” (2023) – evaluated pre-warming, reuse mechanisms, and proposed two-tier edge-cloud FaaS with allocation policies.
4. Prediction-based hybrid scheduling model (Applied to FaaS) – reported buffer-aware approach reducing cold starts to 7–14%, improving container utilization to >80%, and cutting container count up to 60%, but increasing queuing delays.
5. MDPI study on containerized parallel tasks – observed ~40× speedup for parallel serverless execution compared to sequential VM execution, and ~23× vs parallel VM execution.