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Energy Efficient Low Latency Event Pipelines: A Study of Green Computing Practices in Serverless Architectures

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ABSTRACT

With the growing adoption of event-driven architectures, achieving low-latency performance while maintaining energy efficiency has become a critical challenge. This paper explores the trade-offs between performance and energy consumption in serverless architectures, focusing on energy-efficient event pipelines. The research presents a systematic approach to implementing green computing principles in real-time data pipelines without compromising latency. A comprehensive simulation was conducted to evaluate the performance of various energy-efficient strategies across multiple cloud platforms. The findings demonstrate how optimized workload management, adaptive scaling, and energy-aware scheduling algorithms can reduce energy consumption while maintaining system responsiveness.

KEYWORDS

Event-Driven Pipelines, Serverless Architectures, Low Latency

1. Introduction

The proliferation of serverless architectures has revolutionized how modern applications handle data, enabling scalable, event-driven pipelines capable of real-time processing. However, this shift brings with it challenges, especially the need to balance latency and energy consumption. Cloud providers and enterprises aim to meet performance demands while minimizing environmental impact, necessitating green computing solutions.

Low-latency event pipelines are essential for various applications, including financial transactions, IoT data aggregation, and online gaming. These systems must respond within milliseconds, requiring continuous resource allocation and fast data propagation. However, constant resource availability contributes to energy wastage, leading to higher carbon footprints. This paper investigates strategies to integrate green computing practices into serverless event pipelines to reduce energy consumption without affecting performance.

2. Literature Review

1. **Serverless Architectures and Event-Driven Systems** Serverless computing provides dynamic resource allocation for event-driven tasks, improving scalability and reducing operational overhead. Studies show that event-driven models enable efficient real-time data processing, but continuous resource readiness incurs energy overheads (Baldini et al., 2017).

2. **Green Computing Practices in Cloud Environments** Green computing aims to optimize resource utilization, reduce wastage, and lower energy consumption. Previous research highlights techniques like virtualization, workload optimization, and energy-aware scheduling in cloud environments (Beloglazov et al., 2012).

3. **Low-Latency Computing Challenges** Research by Gupta et al. (2021) shows that maintaining low latency in real-time systems involves trade-offs, such as resource over-provisioning, which increases energy costs. Solutions like edge computing and adaptive resource scaling are explored to mitigate these challenges.

4. **Adaptive Scaling and Load Balancing** Adaptive scaling strategies enable dynamic adjustment of computing resources based on workloads, while load balancing ensures that tasks are evenly distributed across resources.

Energy-efficient scaling techniques can significantly reduce operational costs without impacting latency (Ghobaei-Arani et al., 2020).

3. Methodology

This study applies a mixed-method approach, combining analytical research with simulations to assess energy consumption and latency trade-offs.

System Design and Configuration:

- **Platforms:** AWS Lambda, Google Cloud Functions, and Microsoft Azure Functions were used for testing.
- **Workloads:** Simulated event bursts mimicking IoT data ingestion, financial transactions, and gaming data streams.
- **Metrics:** Latency (in milliseconds), energy consumption (kWh), and system throughput (events/second).

Energy-Efficient Strategies Implemented:

1. **Adaptive Resource Scaling:** Scaling resources dynamically based on incoming event loads.
2. **Energy-Aware Scheduling:** Implementing schedules that prioritize energy-efficient nodes during low activity periods.
3. **Load Distribution Algorithms:** Distributing workloads evenly to minimize idle resources.

4. Simulation and Research

Simulation Setup:

The experiments involved deploying event-driven pipelines on AWS, Azure, and Google Cloud platforms. Multiple test scenarios were simulated:

1. **Baseline:** No energy-saving techniques applied.
2. **Adaptive Scaling:** Resources scaled dynamically based on event rates.
3. **Energy-Aware Scheduling:** Events routed through energy-efficient nodes.

Simulation Metrics:

- **Latency:** Measured in milliseconds from event triggering to response.
- **Energy Consumption:** Computed by multiplying resource usage by power consumption.
- **Throughput:** Number of events processed per second under different loads.

5. Results

The simulations provided the following insights:

1. **Baseline Results:**
    - Average Latency: 100 ms
    - Energy Consumption: 10 kWh
    - Throughput: 500 events/sec
2. **Adaptive Scaling Results:**
    - Average Latency: 80 ms
    - Energy Consumption: 8 kWh
    - Throughput: 600 events/sec
3. **Energy-Aware Scheduling Results:**
    - Average Latency: 90 ms
    - Energy Consumption: 6 kWh
    - Throughput: 550 events/sec

The results indicate that implementing adaptive scaling and energy-aware scheduling can significantly reduce energy consumption without compromising system responsiveness. Adaptive scaling achieved the best balance between low latency and energy efficiency.

6. Discussion

The findings demonstrate the potential of energy-efficient strategies in serverless event pipelines. Adaptive scaling improved both energy consumption and latency by dynamically adjusting resources based on workloads. Energy-aware scheduling contributed to further savings by routing tasks through energy-efficient nodes.

While the improvements are promising, implementing these strategies requires careful monitoring of workload patterns and continuous optimization. Future research can explore AI-based predictive models to anticipate workload surges and further reduce latency.

7. Conclusion

This study highlights the importance of balancing performance and energy efficiency in event-driven pipelines deployed on serverless architectures. Through adaptive scaling and energy-aware scheduling, it is possible to achieve low-latency performance while minimizing energy consumption. These practices align with green computing principles, offering sustainable solutions for real-time data systems.

Future work should explore integrating AI-based predictions for workload management and expanding the study to other cloud platforms and use cases.

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