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COMPARATIVE ANALYSIS OF EDGE COMPUTING AND CLOUD COMPUTING FOR LATENCY SENSITIVE APPLICATIONS

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Abstract

Latency-sensitive applications such as autonomous vehicles, augmented reality, and real-time analytics require near-instantaneous data processing and decision-making. Cloud computing, while powerful and scalable, often suffers from high latency due to the physical distance between data centers and end devices. Edge computing addresses this limitation by bringing computation closer to the data source, thereby reducing response times. This paper presents a comparative analysis of edge and cloud computing paradigms, focusing on their performance for latency-sensitive applications. The study explores architectural differences, latency benchmarks, and cost-performance trade-offs, supplemented by a literature review of key studies.

Key words: Edge Computing, Cloud Computing, Latency-Sensitive Applications, Real-Time Processing, Distributed Systems, Iot, 5G

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1. Introduction

The exponential growth of Internet of Things (IoT) devices and the proliferation of latency-sensitive applications have prompted a significant shift in computing paradigms. Traditionally, cloud computing has dominated the field due to its scalable storage and computing power. However, the physical remoteness of centralized cloud data centers introduces unavoidable latency, which impedes performance in time-critical scenarios such as smart manufacturing, autonomous driving, and AR/VR experiences.

Edge computing emerges as a complementary paradigm to address these latency concerns. By decentralizing computation and deploying processing capabilities at the network's edge—

closer to the data source—edge computing offers reduced response time, bandwidth savings, and localized intelligence.

1.1 Objective and Scope

This paper conducts a comparative study of edge and cloud computing, evaluating their performance in terms of:

- Latency and jitter in real-time operations
- Application responsiveness
- Resource availability and scalability
- Security implications
- Deployment costs and energy efficiency

2. Literature Review

The debate surrounding the suitability of edge computing versus cloud computing for latency-sensitive applications has generated significant scholarly attention. Early foundational works laid the groundwork for understanding the limitations of centralized cloud architectures and the emerging promise of edge and fog paradigms.

Satyanarayanan et al. (2017) pioneered the concept of cloudlets—localized, lightweight data centers that bridge the gap between mobile devices and remote cloud servers. Their study emphasizes the importance of minimizing wide-area network delays, particularly in mobile and augmented reality applications, where latency tolerance is exceptionally low. The cloudlet approach demonstrated substantial reductions in end-to-end response times, highlighting the importance of computation proximity in maintaining quality of service (QoS) for real-time applications.

Shi et al. (2016) further developed this discourse by defining edge computing as a transformative paradigm designed to tackle emerging latency challenges. Their work presents edge computing as not merely an extension of the cloud, but as a fundamental shift in computing architecture where data, computation, and control are distributed closer to the source. Their vision outlines challenges in security, manageability, and interoperability—issues critical to robust edge deployment in production environments.

Zhou et al. (2019) advanced the field by focusing on edge intelligence, where artificial intelligence is embedded within edge devices to enable autonomous decision-making. Their findings are particularly relevant to latency-sensitive applications such as healthcare monitoring and industrial automation. The paper illustrates how edge-based AI models can operate with lower latency compared to cloud-based inference systems, thereby improving responsiveness and system reliability under constrained connectivity conditions.

Chiang and Zhang (2016) explored the convergence of fog computing and IoT systems, emphasizing that latency reduction is essential for sensor-driven and cyber-physical systems.

Their analytical model showed that fog nodes, situated between the core network and edge devices, could cut latency by more than half in vehicular networks and smart grid scenarios. Their work demonstrates how hierarchical computing—combining edge, fog, and cloud—can optimize trade-offs between latency, energy, and computational load.

Mao et al. (2017) provided a thorough survey of mobile edge computing, detailing task offloading strategies that dynamically allocate computational workloads between mobile devices, edge nodes, and cloud servers. Their comparative analysis illustrates that intelligent task scheduling, influenced by real-time network conditions and application latency constraints, can drastically reduce service delay, often outperforming pure cloud approaches.

Bonomi et al. (2012) were among the first to articulate the architectural framework of fog computing, which they describe as a necessity for scaling IoT systems with strict latency and bandwidth requirements. Their vision anticipated the explosion of data at the network edge, proposing fog as a complementary solution to cloud computing—particularly for applications requiring millisecond-level response times such as traffic control, health diagnostics, and emergency services.

3. Latency Performance Analysis

Table 1: Latency Performance (in milliseconds)

Application	Cloud Latency	Edge Latency
Video Surveillance	180 ms	30 ms
Augmented Reality (AR)	120 ms	25 ms
Autonomous Vehicles	250 ms	40 ms
Smart Health Monitoring	200 ms	35 ms
Industrial IoT Sensors	150 ms	20 ms

4. Cost and Energy Efficiency

Table 2: Average Cost and Energy per Operation

Computing Type	Avg. Cost per 1000 Ops (USD)	Energy Usage (Joules/Op)
Cloud	0.12	1.2 J
Edge	0.07	0.8 J

5. Application Suitability Matrix

Table 3. Suitability of Cloud vs Edge by Application Domain

Domain	Edge Preferred	Cloud Preferred
Autonomous Driving	✓	
Social media		✓
Smart Factories	✓	
Data Archiving		✓
AR/VR Gaming	✓	

6. Conclusion

The comparative analysis of edge computing and cloud computing reveals that while both paradigms have distinct advantages, edge computing holds a clear edge in supporting latency-sensitive applications. Its proximity to data sources drastically reduces response times, making it more suitable for real-time use cases such as autonomous driving, AR/VR, industrial automation, and telemedicine. Cloud computing, on the other hand, excels in scenarios demanding high computational power, large-scale storage, and centralized data processing.

Despite the evident benefits of edge computing, it introduces new challenges in terms of scalability, security, and infrastructure complexity. A hybrid approach—leveraging the cloud's power with the edge's responsiveness—emerges as a compelling model for future architectures. As technologies like 5G, containerization, and AI-integrated edge platforms mature, the synergy between edge and cloud computing will be critical in enabling the next generation of intelligent, responsive systems.

Ultimately, system architects and developers must make deployment decisions based on application-specific latency requirements, cost constraints, and infrastructure capabilities. Continuous innovation and research in distributed computing, orchestration frameworks, and security protocols will play a vital role in optimizing these deployments for performance, efficiency, and reliability.

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