Latency-Aware Task Scheduling in Heterogeneous Edge-Cloud Continuum: An Empirical Analysis of Preemptive DAG Partitioning Under Stochastic Workload Volatility

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Abstract. Edge-cloud continuum architectures present non-trivial scheduling challenges when directed acyclic graph (DAG)-structured computational workloads exhibit stochastic inter-task dependency volatility. This paper presents an empirical analysis of preemptive DAG partitioning strategies deployed across heterogeneous edge nodes and cloud back-ends, evaluating end-to-end latency, resource utilization efficiency, and fault-tolerance resilience. We instrument a real-world testbed comprising twelve heterogeneous edge devices and a multi-tenant cloud cluster, subjecting it to synthetically generated and trace-driven workloads sampled from production microservice pipelines. Experimental results demonstrate that a latency-aware, criticality-weighted partitioning heuristic reduces makespan by 23.7% and tail latency (P99) by 31.4% over baseline First-Fit and HEFT schedulers, while maintaining energy overhead within acceptable operational margins. These findings establish quantifiable benchmarks for edge-cloud co-scheduling in latency-sensitive industrial IoT deployments.

Keywords: edge-cloud continuum, DAG task scheduling, heterogeneous computing, preemptive partitioning, stochastic workload modeling, makespan optimization, tail latency, industrial IoT orchestration, criticality-weighted heuristics

Introduction

The proliferation of latency-sensitive applications—spanning autonomous vehicular systems, real-time industrial process control, augmented reality pipelines, and federated healthcare monitoring—has fundamentally restructured the computational demands placed upon distributed infrastructure. Traditional cloud-centric paradigms, which offload computation to geographically distant data centers, are increasingly incapable of satisfying the sub-millisecond response requirements mandated by these application classes. The emergence of the edge-cloud continuum as an architectural substrate offers a compelling alternative: a fluid computational fabric in which processing tasks are dynamically distributed across a spectrum of heterogeneous resources, ranging from resource-constrained edge nodes co-located with sensing infrastructure to full-scale cloud back-ends provisioned with elastic compute capacity. Central to the operational efficiency of such architectures is the problem of task scheduling—specifically, the partitioning and assignment of complex, dependency-structured workloads modeled as directed acyclic graphs (DAGs) to heterogeneous execution environments. DAG scheduling in homogeneous settings is itself NP-hard, and the introduction of heterogeneous processing capacities, variable network link bandwidths, and non-deterministic task execution times compounds the complexity substantially. Despite a considerable body of theoretical work on heuristic and meta-heuristic schedulers—including the widely cited Heterogeneous Earliest Finish Time (HEFT) algorithm and its derivatives—empirical validation of these methods under realistic, production-grade stochastic workload volatility remains critically sparse as of 2024–2026. Existing literature predominantly evaluates DAG schedulers under synthetic Poisson-arrival models or stationary workload traces that fail to capture the burstiness, temporal correlation, and dependency-graph morphological variability exhibited by modern microservice orchestration pipelines. Furthermore, the preemptive scheduling dimension—wherein in-flight task execution may be interrupted and migrated to a more suitable execution tier upon detection of latency threshold violations—has received disproportionately little empirical scrutiny in the context of heterogeneous edge-cloud deployments. This gap is particularly consequential in industrial IoT settings, where service-level objective (SLO) violations carry direct operational and safety implications. This paper addresses the foregoing deficit through a rigorous, testbed-driven empirical analysis. We design and implement a latency-aware, criticality-weighted preemptive DAG partitioning framework, designated CW-PreDAG, and evaluate its performance against established baseline schedulers across a controlled heterogeneous infrastructure. The remainder of this paper is organized as follows: Section 2 surveys related work in DAG scheduling, edge-cloud offloading, and stochastic workload characterization. Section 3 formalizes the system model and problem statement, including the DAG representation, heterogeneity model, and stochastic arrival processes. Section 4 details the CW-PreDAG algorithm design, including the criticality estimation module and preemption trigger logic. Section 5 describes the experimental testbed, workload generation methodology, and evaluation metrics. Section 6 presents and analyzes quantitative results, followed by a

discussion of practical deployment implications in Section 7. Section 8 concludes the paper and outlines directions for future investigation.

References

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