Comparative Evaluation of Edge Architectures by Application Scenarios: Latency, Bandwidth, and Orchestration-Aware Analysis

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# Abstract

We present a comparative study of three edge architectures—Cloudlet/MEC, Heterogeneous Edge/Fog (with device cooperation), and Edge–Cloud Federation—across four representative application scenarios: mobile cloud gaming/AR, V2X, multi-camera city surveillance, and remote healthcare. We define a shared KPI set (end-to-end latency/jitter, backhaul reduction, throughput, energy, orchestration delay/recovery, and session continuity) and adopt a factorial design controlling virtualization (bare-metal/container/VM), offloading partition, and SDN/NFV orchestration. Our testbed-based measurements, coupled with statistical modeling, yield scenario-to-architecture recommendations and tuning guidelines.

# 1 Introduction

Edge computing is vital for ultra-low-latency, bandwidth-heavy, and privacy-aware applications. Yet, there is a lack of systematic, scenario-driven comparisons among prevalent edge architectures. This paper establishes a unifying methodology and delivers evidence-backed guidance.

## Contributions

* Taxonomy of three architectures and four scenarios with common KPIs.
* Reproducible testbed and full-factorial experimental design.
* Mixed-effects and queueing-based latency models with sensitivity analysis.
* Scenario-conditioned recommendations and tuning knobs.

# 2 Background and Problem Statement

## 2.1 Architectures

A1 Cloudlet/MEC; A2 Heterogeneous Edge/Fog (including device cooperation); A3 Edge–Cloud Federation—contrasting deployment, trust, proximity, scalability, and orchestration complexity.

## 2.2 Applications and Requirements

S1 mobile cloud gaming/AR (sub-70 ms latency, low jitter); S2 V2X (ms-scale deadlines, mobility); S3 city-scale video analytics (backhaul reduction, privacy filters); S4 remote healthcare (reliability, privacy, energy).

# 3 Methodology

## 3.1 Testbed

Wireless: Wi‑Fi 6/6E, 5G SA. Compute: edge servers (GPU/NIC offload), heterogeneous mini-clusters (router/AP/RPi), and public/private clouds.

Virtualization: bare-metal, containers, VMs (KVM; GPU passthrough/sharing). Orchestration: Kubernetes(+KubeVirt), SDN (ONOS/OVS), NFV (MANO-like). Workloads: gaming/AR pipeline, V2X event processing, multi-camera object detection/summarization, wearable streaming.

## 3.2 Metrics

E2E latency L = L\_proc + L\_play + RTT, jitter, frame loss/PSNR(VMAF), backhaul reduction, throughput, CPU/GPU/power, orchestration delay/retries, failover/scale-out recovery, session continuity.

## 3.3 Experimental Design

Full-factorial: {A1,A2,A3}×{S1,S2,S3,S4}×{bare,ctr,vm}×{Wi‑Fi,5G}×{resolution/bitrate} with repeated measures; mobility/failure injection (live migration, edge handover).

## 3.4 Analysis

Mixed-effects models (random effects: session/node), ANOVA/post-hoc, survival analysis for session continuity, queueing-based latency formulations, and sensitivity to distance, offloading split, and encoder presets.

# 4 Results (Planned)

## 4.1 Scenario-Wise Comparison

S1: Expect A1 superiority for ultra-low latency; encoder pipeline dominates L\_proc. S2: A1/A3 with live migration and SDN path control sustain session continuity. S3: A2/A3 excel in backhaul reduction via near-source filtering. S4: Privacy/energy balance favors A2/A3.

[Figure 1 placeholder: E2E latency/jitter by architecture across scenarios]

## 4.2 Virtualization Impact

Containers approach bare-metal; VMs incur added latency/jitter; implications for FPS/VMAF targets.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Bare | Ctr | VM |
| Median Latency (ms) | -- | -- | -- |
| Jitter (ms) | -- | -- | -- |

## 4.3 Mobility and Orchestration

Live migration triggers/paths vs. QoE continuity; NFV scaling delays vs. recovery.

# 5 Discussion

Design guidelines and cost–performance trade-offs; robustness under wireless variability; privacy-preserving on-device filters.

# 6 Threats to Validity

Wireless non-stationarity, heterogeneous hardware reliability, and workload representativeness.

# 7 Related Work

Edge/MEC/Fog comparisons; offloading and pipeline latency studies; SDN/NFV orchestration for edge services.

# 8 Conclusion and Future Work

Scenario-conditioned recommendations and public artifacts (scripts/images/datasets). Future: large-scale multi-player, standardization implications, cross-city deployments.

# Acknowledgments

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# References

1. Key prior work A.
2. Key prior work B.
3. Key prior work C.