The Evolution of Cloud Computing: A Comparative Study from Virtualization to Serverless Architectures

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ABSTRACT

The evolution of cloud computing from virtualiza- tion to serverless paradigms has transformed the way applications are deployed, scaled, and managed across distributed environments. Over the years, this transformation has introduced new architectural models that focus on automation, elasticity, and efficiency. Virtual machines provided strong isolation but suffered from high overhead, while containerization improved portability and accelerated application delivery. The latest shift toward serverless computing reduces operational burden by enabling event-driven execution without manual infrastructure management. This review examines research involving serverless platforms and their integration with Network Function Virtu- alization (NFV), Software-Defined Networking (SDN), and edge computing. Studies report significant benefits such as fine-grained autoscaling, cost-efficient execution, simplified orchestration, and faster development cycles. At the same time, challenges like cold-start latency, multi-tenant performance interference, QoS variability, dependency security issues, and the risk of vendor lock-in continue to limit Overall. Existing literature suggests that combining serverless models with virtualization and container techniques can create hybrid cloud environments that deliver better performance stability, improved resource utilization, and stronger flexibility for modern, data-intensive applications.

Keywords: Serverless Computing, Cloud Computing, Net- work Function Virtualization (NFV), Function as a Service (FaaS), Scalability, Hybrid Serverless Platform (HSP)

INTRODUCTION

The landscape of cloud computing has evolved signifi- cantly, shifting from rigid virtualization techniques toward agile container-based and serverless frameworks. Initially, the industry relied heavily on virtualization, employing hyper- visors to host multiple virtual machines (VMs) on shared hardware to ensure system isolation and maximize resource efficiency. While this technology established the foundation for modern Infrastructure-as-a-Service (IaaS) models, it eventually struggled to keep pace with dynamic application workloads. Critics and practitioners alike noted that traditional virtualiza- tion suffered from operational complexity, slow provisioning speeds, and excessive resource overhead.

In response to these inefficiencies, the focus turned to- ward microservices and containerization. Containers offered a lightweight alternative, delivering rapid startup capabili- ties and superior portability that proved essential for scal- able, cloud-native environments. This trajectory culminated in the emergence of serverless computing, or Function-as-a- Service (FaaS). By abstracting away infrastructure manage- ment, serverless platforms automatically handle the provi- sioning, execution, and scaling of code. While this paradigm offers distinct advantages in developer productivity and cost optimization, it is not without drawbacks; persistent challenges include security vulnerabilities, potential vendor lock-in, and ”cold-start” latency.

More recently, research has expanded the scope of serverless computing into hybrid cloud and edge environments. For instance, Sabbioni et al. developed a QoS-aware framework for Network Function Virtualization (NFV) at the edge, suc- cessfully demonstrating reduced latency in environments with limited resources [2]. Furthermore, hybrid architectures that blend IaaS with serverless models have yielded improve- ments in service-function-chain performance by optimizing the placement and scaling of Virtual Network Functions (VNFs) [3]. Collectively, current literature highlights a decisive move away from heavy, VM-centric systems toward distributed, event-driven, and lightweight architectures. Although this tran- sition enhances elasticity and performance, it complicates orchestration and security consistency. Consequently, there is a growing necessity for edge-optimized and hybrid serverless solutions that can effectively balance reliability, scalability, and efficiency.

Evolution from Virtualization to Serverless Computing

Cloud computing has transitioned from virtualization- centric architectures to serverless paradigms. As Gadani (2023) stated, “Serverless computing revolutionized cloud infrastructure by eliminating the need for infrastructure man- agement” (Gadani, 2023, Journal of Emerging Technologies and Innovative Research). This shift is driven by the growing demand for scalability, efficiency, and reduced operational complexity. Virtualization formed the foundation of cloud infrastructure by enabling multiple virtual machines (VMs) to share a single physical server, improving resource utiliza- tion, isolation, and cost efficiency for large enterprises [22]. This model allowed companies such as Amazon, Google, and Microsoft to build massive data centers with optimized hardware utilization and flexible Infrastructure-as-a-Service (IaaS) offerings.

As applications became more dynamic and event-driven, virtualization was complemented by lightweight containers and eventually evolved into Function-as-a-Service (FaaS), also known as serverless computing. Cloud providers now offer managed databases, storage, authentication, and messaging services that integrate directly with serverless functions. This reduces manual work and accelerates application development [1].

LITERATURE REVIEW

Cloud computing has evolved through several phases, start- ing from virtualization and moving toward containerization, microservices, and finally serverless and edge-based architec- tures. Several researchers have analyzed these transitions and highlighted both benefits and challenges at each stage.

Serverless Benefits and Drawbacks

Rajan (2020) explained that serverless computing reduces operational cost and simplifies application deployment by eliminating the need to manage servers manually. This work shows how FaaS platforms automate scaling and resource allo- cation, making them suitable for event-driven workloads [16]. However, Rajan also noted cold-start delays and monitoring limitations as major drawbacks of serverless environments. Kodakandla (2021) compared commercial serverless platforms (AWS Lambda, Google Cloud Functions, Azure Functions), revealing significant differences in cold-start behavior, scal- ability, and pricing, highlighting the need for standardized benchmarks [21]. Fernandez et al. (2021) evaluated multiple serverless platforms and found inconsistencies in execution time, networking delays, and memory usage. Their study stressed the need for improved predictability in serverless environments, especially for real-time workloads [18].

Serverless and Edge Integration

Chaudhry et al. (2020) studied serverless computing at the network edge and found that integrating serverless execu- tion with Network Function Virtualization (NFV) significantly improves latency and energy efficiency [12]. Their work demonstrated that replacing VM-based VNFs with lightweight functions can provide better Quality of Service (QoS) for edge applications. Sabbioni et al. (2024) developed a QoS-aware middleware called TEMPOS4NFV, which manages serverless functions in resource-constrained edge environments [2]. The study showed that intelligent VNF orchestration can reduce processing delays and support time-critical services, suggest- ing that serverless frameworks can extend beyond centralized cloud systems [17].

Hybrid and Lightweight Architectures

Andreoli et al. (2025) focused on time-critical cloud systems and highlighted that traditional VM-based services struggle to meet strict latency requirements [4]. Their research supports the shift toward lightweight, event-driven architectures that can adapt dynamically to varying workloads. Li et al. (2022) introduced TeleVM, a lightweight virtual machine designed for RISC-V architectures, offering faster boot times and stronger isolation compared to conventional VMs [20]. TeleVM's per- formance demonstrates that hybrid systems combining microVMs and serverless orchestration can balance efficiency and security. Patel et al. (2017) compared the performance and cost of VMs, containers, and serverless platforms and con- cluded that while serverless systems are more cost-effective for variable workloads, VMs remain beneficial for long-running tasks [6]. These results highlight the importance of hybrid deployment models. Ramesh and Nair (2024) emphasized that virtualization still plays an important role in cloud workloads requiring strong isolation and high security [23].

Performance and Isolation

Gajanin et al. (2025) examined performance isolation in multi-tenant serverless systems and observed unpredictable delays when several functions run simultaneously [15]. Their findings underline the importance of resource scheduling and QoS management in FaaS platforms.

Overall, the literature indicates a clear trend: cloud comput- ing is moving from heavy virtualization models to lightweight, automated, and event-driven serverless architectures. Research also shows a growing focus on hybrid solutions combin- ing VMs, containers, microVMs, and serverless platforms to achieve better performance, security, and scalability. While serverless computing offers many advantages, there is still a need to improve cold-start delays, performance isolation, and interoperability between cloud and edge environments [25].

Impact on Cloud Architecture

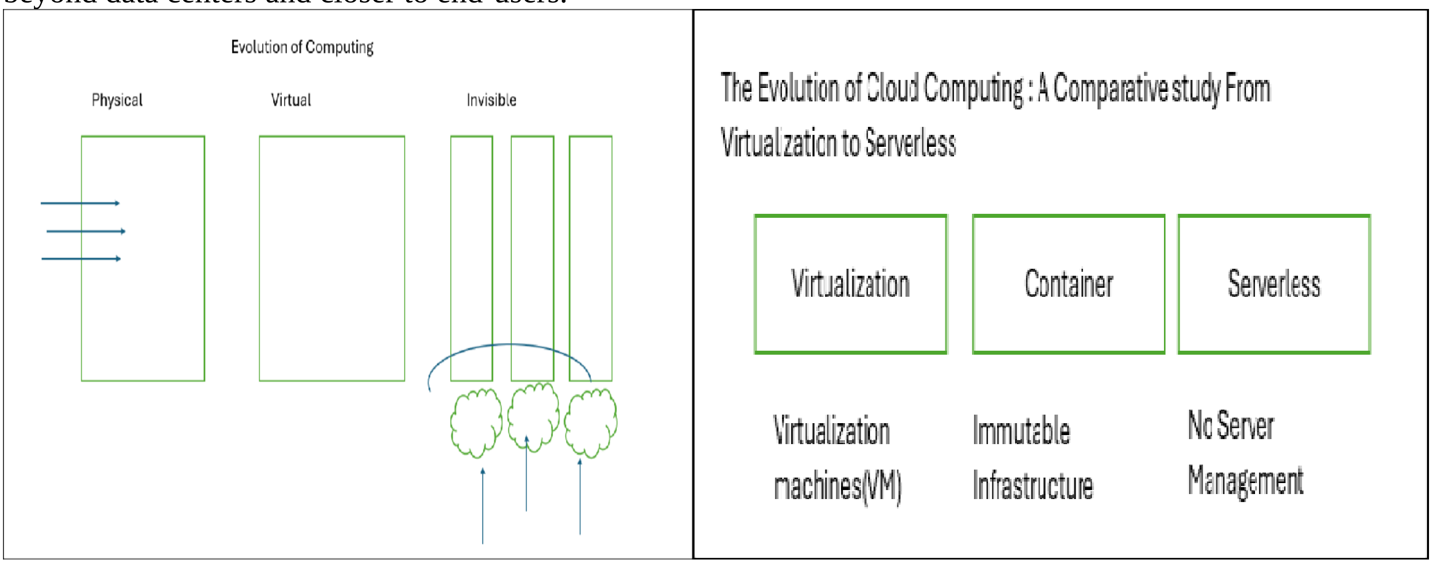
The evolution of cloud computing has driven significant changes in architectural practices.

Immutable Infrastructure and CI/CD Pipelines

The shift from VMs to containers has promoted immutable infrastructure practices, where servers or containers are not modified post-deployment. Updates are rolled out as new versions through CI/CD pipelines, enhancing consistency and reliability.

Multi-Cloud and Hybrid Strategies

Container portability allows applications to be deployed across different cloud providers or on-premises environments with minimal reconfiguration, supporting multi-cloud and hy- brid cloud approaches [10]. Modern container platforms come with built-in tools that help monitor logs, performance, and resource usage. This improves visibility and helps teams quickly detect and fix issues [26]. Containers are lightweight and portable, making them suitable even for edge devices and serverless platforms [24]. This expands the cloud architecture beyond data centers and closer to end-users.



a) Evolution from Virtualization to Serverless (b) Detailed Evolution of Computing

Fig. 1: Conceptual Diagrams of Cloud Computing Evolution: (a) Simple stages, (b) The transition from physical to invisible infrastructure.

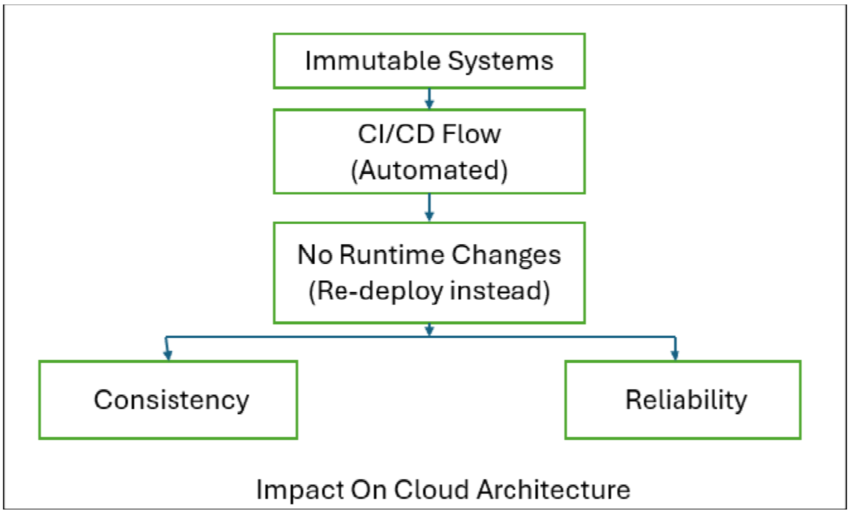


Fig. 2: Impact of Immutable Systems on Cloud Architecture

Real-world Metrics

A comparison of the cost and suitability of EC2 (instance- alive model) versus Serverless (invocation model) for different workloads is provided in Table I [27].

TABLE I: Comparative Cost and Preference Metrics for Cloud Workloads

Scenario	Workload Type	EC2 (instance alive mod)
Low traffic / intermittent	e.g., 100k requests/month	~$7.49/month
Medium traffic	e.g., 1-2 M/month	maybe ~$14.98/month
High traffic / constant	e.g., 10M+ requests/month	~$29.95/month
Idle-heavy background job	e.g., runs 200ms every 5 min	~$8.50/month*

Future Scope

Future research and development should focus on several key areas to mature the serverless ecosystem:

- **Hybrid Orchestration Frameworks:** Develop intelli- gent frameworks to switch workloads between VMs, containers, and serverless platforms based on real-time performance, cost, and resource utilization [14].

- **Standardized Benchmarking Models:** Create unified benchmarks to compare virtualization, containerization, and serverless systems under similar workloads [9].

- **Enhanced Serverless Security:** Investigate lightweight isolation mechanisms, zero-trust architectures, and AI- driven anomaly detection to strengthen security in server- less environments [19].

- **Lightweight Virtualization:** Explore technologies such as TeleVM and microVMs to improve efficiency, respon- siveness, and isolation in edge and IoT deployments [13].

- **Automated Migration Tools:** Design tools to automate the transition from traditional virtualized infrastructure to event-driven serverless systems while maintaining relia- bility and compliance [8].

CONCLUSION

Cloud computing has evolved from virtualization-based sys- tems offering strong isolation but high overhead, to container- ized environments emphasizing portability and efficiency, and finally to serverless computing providing agility, scalability, and cost-effectiveness. Studies by Rajan (2020), Chaudhry et al. (2020) [12], and Li et al. (2022) [20] show that each stage solves certain challenges while introducing others, particu- larly in performance consistency, security, and orchestration complexity. Despite progress, existing research is fragmented, highlighting the need for integrated, performance-aware, and security-oriented hybrid cloud frameworks to guide the tran- sition from virtualization to serverless computing.

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