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An In-Depth Review of Cost Optimization Tactics in Multi-Cloud Frameworks

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Abstract: *The emergence of multi-cloud architectures, which rely on a heterogeneous combination of cloud providers to ensure resiliency and flexibility, has been of paramount concern to contemporary enterprise IT strategy. The present paper includes a literature overview of cost optimization strategies in the case of multi-clouds, their scales of balance between best performance and scalability, and cost-effectiveness. While multi-cloud computing offers more flexibility in terms of resource convergence between providers, it also introduces numerous obstacles to cost management strategies. Research delves into important cost aspects including Total Cost of Ownership (TCO) and Transaction Cost Economics (TCE), while also exploring different cloud deployment alternatives like public, private, hybrid, and multi-cloud strategies. Discussed are methods for lowering operational and capital costs, such as downsizing, properly acquired servers, virtual machines, and migration capabilities. The thorough literature review evaluates heuristic algorithms, online optimization tools, and the prediction models that enhance the better usage of resources and cost-effective performance. Another prevailing issue addressed in the paper is that of dependence on the heuristics, the problem of scalability, and complexity of the models. Lastly, it highlights why there is an urgent necessity to drive cost management practice into multi-cloud environments and thus to improve the efficiency of operations.*

Keywords: Multi Cloud, Cost Optimization, Total Cost of Ownership (TCO), Transaction Cost Economics (TCE), Virtual Machine Migration

I. INTRODUCTION

Consumer interest in data-intensive services has skyrocketed thanks in large part to cloud computing's spectacular ascent. Both academics and businesses have recently taken an interest in cloud service portfolios. Cloud computing platforms offer the optimal computational paradigm for meeting user needs simultaneously by merging various resources [1]. With a multi-provider multi-service system design, users' requests are typically satisfied by simulating the service execution process on clouds [2]. To ensure that a cloud-based solution lives up to customer service expectations, it is possible to integrate many clouds and services from various suppliers into an interconnected set of services [3].

Multiple clouds are an advanced kind of heterogeneous cloud computing or fog. Many different approaches, services, deployment models, cloud platforms, and cloud architectures built by different vendors make up what is known as a multi-cloud infrastructure. With multi-cloud, users in various environments may grow and manage on-demand services with ease [4]. Even if it has a lot of limitations, multi-cloud allows customers to decide who has access to what data or services over the internet and makes it more secure. One way that multi-cloud deployment helps cloud service providers decrease energy consumption and cybersecurity issues is by allowing transparent access control over the hosted services and apps [5].

Measuring and assessing cloud resource utilization is crucial for cost control. Three common types of resources that need assessment in IaaS are the central processing unit (CPU), the network, and the storage. For central processing unit (CPU) models, processing power determines the base price, and unit pricing and service time determine the cost. When it comes to the resources available on the network, the amount of data transmitted is evaluated and charged accordingly [6][7]. When it comes to storage resources, all that matters is the amount of I/O operations and storage volumes used together, and their cost is determined by that [8]. Only optimization objectives like cost, time, and quality are taken into

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account when allocating production resources. Optimization allocation models for manufacturing resources fall short in meeting modern industry demands because they fail to take cloud manufacturing resource allocation's adaptability to unexpected implementation outcomes into consideration [9].

There are typically two ways to buy cloud computing instances from cloud providers. The first choice is an instance that is on-demand and is billed on an hourly basis. The alternative is a reserved instance, in which a client must pay ahead of time for a specific duration of service [10]. However, because of the unpredictability of future consumer demand and supplier resource pricing, it is challenging to implement the optimal advance reservation strategy [11]. Furthermore, cloud providers frequently give a wide variety of instances with varying amounts of processing power. After that, the customer may choose the instance types that best suit their needs.

A. Structure of the Paper

The structure of this paper follows as: Section I introduces multi-cloud and its cost challenges. Section II covers multi-cloud models/types. Section III outlines cost components IN Multi-Cloud Infrastructure. Section IV details cost optimization strategies. Section V reviews related studies. Section VI gives conclusions and future directions.

II. MULTIPLE TYPES OF CLOUD ENVIRONMENTS

The computer and Internet environment is changing as a result of cloud computing. Cloud computing's position as the foundation for IT services undoubtedly grow as proper service and business model advancements are implemented. It is a novel idea whose technical manifestation is expected to transform how people live and work [12]. Cloud computing, with its pay-per-use pricing model, offers elastic and limitless resources that may be effectively exploited under regular and peak loads [13]. Figure 1 illustrates the four Cloud Deployment Models that focus on certain requirements.:

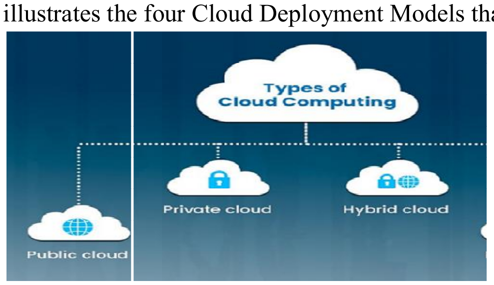

Figure 1: Multiple Types of Cloud

A. Public Cloud

The fundamental hardware and software of public clouds is owned by the cloud provider. The infrastructure for the cloud is housed at the provider's facilities. The cloud services are available for pay-as-you-use to either the general public or a sizable industrial organization. On demand, the cloud's resources are distributed to the consumers. As seen in Figure 2, the resources are made available online in a dynamic manner. The use of public clouds is very beneficial for small and medium-sized businesses (SMEs) [14][15]. Public clouds provide the following benefits high scalability, utility-style costing, flexibility, dependability, cost-effectiveness, and geographical independence. Less customization and poor security are drawbacks.

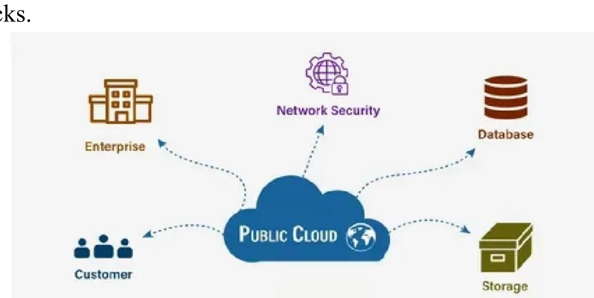

Figure 2: Public Cloud Environment

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Privacy: The issue with using a public cloud is that it may not know the exact location of your data, its backup procedures, or the likelihood that unauthorized people can access it. The reliability of public cloud networks is another concern [16]. As an example, a recent two-day Amazon cloud outage rendered hundreds of large e-commerce websites inaccessible or non-functional.

B. Private Cloud

Computing in a private cloud, as shown in Figure 3, allows your business to make use of its unique resources. Private clouds have the same characteristics as public clouds, including resource pooling, self-service, elasticity, and pay-as-you-go, but with the advantages of dedicated resources, such as greater control and customisation [17]. Both on-premises and off-site private clouds are available in the private cloud market.

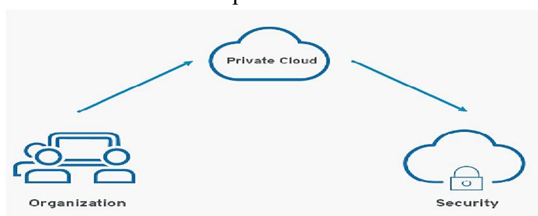

Figure 3: Private Cloud Environment

Here are the two Variants of private cloud are as:

On-Premise Private Cloud

Cloud computing that is housed on-premises, sometimes called a "internal cloud," is located in the data centre that the business owns. Although it offers better safety and a more uniform procedure, its size and scalability are frequently constrained. A company's information technology department would also be held liable for the initial investment and ongoing maintenance of physical assets under this model [18][19]. When it comes to infrastructure and security settings, on-premise private clouds are the way to go for applications that require complete control.

Externally Hosted Private Cloud

An organization uses the externally hosted private cloud model when it hires a cloud service provider to handle the private cloud implementation [20][10]. The external provider's facilities house the cloud infrastructure rather than the customer organizations.

C. Hybrid Cloud

The hybrid cloud is the trickiest to set up because it combines public and private clouds that are connected with either custom or standard technologies. This allows data and applications to be transferred [21]. Hybrid cloud services are effective because, as Figure 4 illustrates, it allows companies more control over their personal information.

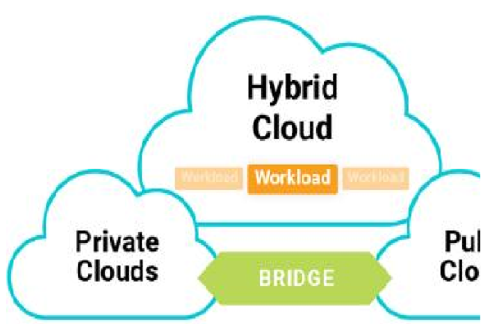

Figure 4: Hybrid Cloud Environment

Why Hybrid Cloud Required

Hybrid cloud means different services to different people. The needs of an organization depend on diverse aspects of IT [22]. As the perspectives of application designers, business developers, and infrastructure support personnel are different from one another, their expectations of the system also vary.

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Multi-Cloud

Multi-cloud refers to cloud systems where applications and workloads are distributed across multiple, distinct cloud service providers. Unlike hybrid clouds which combine private and public clouds as deployment methods multi-cloud environments consist of completely separate and heterogeneous cloud platforms, as illustrated in Figure 5. Each cloud in a multi-cloud setup operates independently with its own infrastructure and services. It is important to note that the term “multi-cloud” is sometimes used broadly or interchangeably with other multi-cloud concepts, which can cause ambiguity [23]. In this context, multi-cloud specifically emphasizes using several distinct cloud providers to maximize cost, availability, or performance [24].

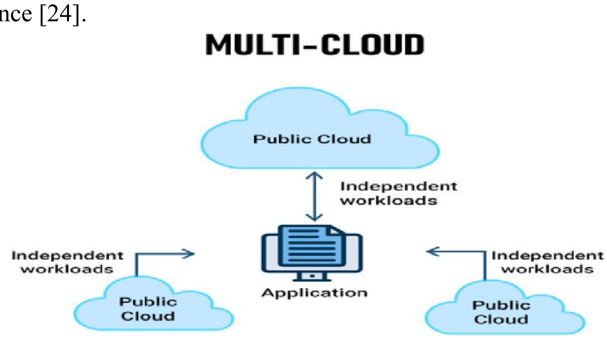

Figure 5: Multi-Cloud Environment

Here are the Cloud Deployment Patterns are in given below:

- **Cloud Busting:** Cloud bursting is a popular and easy-to-understand approach for hybrid and multi-cloud environments. Using this model, a private cloud application "bursts" onto a public cloud when its processing power requirements spike [25].
- **Federated cloud:** A cloud provider in a federated cloud scenario both offers excess capacity to other providers and subcontracts some of its own capacity from other providers.

Table I inspects various cloud models on the basis of ownership, scalability, security, cost, and common use cases. The models include public, private, hybrid, and multi-cloud options. Hybrid clouds strike a balance between scalability and the requirement to protect sensitive data. Public clouds are inexpensive and easy for SMEs to use, private clouds are more expensive but give better security and customization, and multi-clouds employ different suppliers to avoid vendor lock-in but need careful administration [26]. Variants like cloud bursting and federated clouds showcase multi-cloud deployment patterns, which are given below

Table 1: Comparative Overview of Multiple Cloud Environments

Aspect	Public Cloud	Private Cloud	Hybrid Cloud	Multi-Cloud
Ownership	Supervised by a cloud provider (like Amazon Web Services or Microsoft Azure)	Owned by a single organization (internal or externally hosted)	Integration of both private and public cloud resources	Multiple cloud vendors (public and/or private)
Infrastructure Location	Provider’s data centres	On-premises or with external host	Mix of on-premises and public infrastructure	Distributed across multiple providers
Accessibility	Available to the general public or multiple clients	Restricted to one organization	Controlled access within the organization	Varies; coordinated across several vendors
Scalability	High, on-demand scalability	Limited by in-house resources	Flexible public cloud expands when needed	Highly scalable across multiple services
Security	Generally lower than private cloud	High, dedicated infrastructure	Balanced sensitive data kept private, other workloads public	Depends on vendor security and integration
Customization	Low customization	High customization	Moderate mix of standard and custom options	Varies by vendor and integration level
Cost	Pay-per-use, cost-	High capital and	Balanced optimizes	It may be costly if not

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Efficiency	effective for SMEs	operating costs	cost by using both models	managed well
Use Case Examples	Startups, SMEs, SaaS, web hosting	Banking, government, compliance-heavy enterprises	Organizations needing flexibility with sensitive data	Enterprises avoiding vendor lock-in, using specialized tools
Variants	None	On-premises & externally hosted	Integrated via proprietary or open-source tools	Cloud bursting, federated clouds

III. COST COMPONENTS IN MULTI-CLOUD INFRASTRUCTURE

The variable charges in a cloud system would vary monthly based on consumption. Both fixed and variable costs can be found in semi-variable or mixed costs. A change in cost models has also been brought about by the advent of cloud computing in comparison to a typical data Centre [27]. It is stated that labor or fixed expenses accounted for the great bulk of IT investments in the past [28]. However, a variable cost component is taking the place of this conventional fixed cost in the cloud.

A. Total Cost of Ownership (TCO)

Strict sense, total cost of ownership (TCO) is the sum of the capital expenditures (CapEx) paid to acquire an item and the operating expenses (OpEx) incurred by the cloud. When selecting options, SPs should consider both TCO components in order to correctly assess the investment [29]. Cloud TCO estimates frequently overlook migration expenses, despite the fact that they might be significant and alter the total return on investment:

Insights of TCO

Total cost of ownership (TCO) gives businesses a thorough picture of all the costs, allowing them to make smarter decisions. It is imperative that cloud beneficiaries use the TCO approach to cloud computing in order to account for indirect and lifelong expenses and prevent imprecise estimates of the additional value.

Transaction Cost Economics

There are always at least two parties in a commercial contract. A transaction takes place whenever a seller and a consumer engage with one another. A vendor receives payment from a consumer when they purchase an item or service from them. But the price is not the only factor in the cost of the purchased commodity or service [30]. The act of purchasing a commodity or service entails expenses. The expenses associated with overseeing, supervising, and regulating a transaction are referred to as transaction costs [31].

B. Cost Optimization in Cloud Resource

To maintain service availability, cloud systems must adapt to fluctuating resource demands by adjusting resource configurations through scaling. Scaling can occur either vertically (scaling up), such as increasing the CPU capacity of a virtual machine, or horizontally (scaling out), by adding additional instances of the VM [32][33]. Depending on the cloud provider's pricing model, one approach may be more cost-effective than the other while delivering equivalent computing power. Since scaling operations require time to take effect, proactive resource usage prediction is essential to initiate scaling before demand spikes, ensuring both performance and cost efficiency [34].

C. Rightsizing and Auto-Scaling

Rightsizing is the process of modifying cloud resources to closely resemble the needs of a real application, preventing waste from over-provisioning [35]. Organizations achieve this by continuously monitoring usage patterns and scaling resources up or down as necessary. Auto-scaling enhances this approach by dynamically adjusting capacity in response to changes in demand in real time, minimizing idle resource costs while ensuring optimal performance during peak periods [36].

IV. STRATEGIES FOR OPTIMIZATION COST

The goal of cost optimization in multi-cloud settings is to cut waste without sacrificing functionality. It entails choosing the most economical price structures and resources from many suppliers. Maximum return on cloud investments is ensured by effective management. Here are the cost optimization strategies are as follows:

- **Server purchase:** When the virtual machine's needs are not met by the available server resources, the data centre's capacity is increased, which entails buying a server. Purchasing a low-cost solution that satisfies the server's resource needs is the greatest way to reduce hardware overhead. Optimizing the cost of the worldwide request is challenging because of the limitations of some computer resources [37]. This approach prevents overinvestment in infrastructure while meeting workload requirements.
- **Virtual machine deployment:** The FFD technique for virtual machine deployment can also optimize the hardware overhead. An effective deployment plan can save the need to purchase more servers and guarantee that current resources are utilized effectively. This decreases capital and operating costs and enhances resource allocation.
- **Virtual Machine Migration Strategy:** Servers may continue to work, but in a low-capacity state, in a cases where many deletion requests are made. Virtual server migration assists in the workload consolidation with possible server deactivation. This method reduces energy use and operational expenses. It enhances infrastructure overall efficiencies and load balancing as well.

V. LITERATURE REVIEW

This review of the literature examines ways to reduce expenses in multi-cloud contexts through heuristic algorithms, online techniques, and models of optimization. These strategies reduce hardware and migration cost, and storage costs along with improving performance and scalability, and resource efficiency.

Fé et al. (2022) a solution that would simulate auto-scaling activities in a typical cloud infrastructure using a stochastic Petri net (SPN) and a well-known adaptive search metaheuristic (GRASP) to identify important performance-versus-cost trade-offs in cloud services. Designing cloud services with the suggested SPN models allows for estimation of numerous parameters, including the optimal configuration, costs, system response time, and throughput, among many others. The most cost-effective system configuration and parameterization can be determined with an optimization algorithm to address the critical SLA (and financial) requirements. The developed auto-scaling mechanisms modelled in this work and the metaheuristic method based on the GRASP technique support the search for the best-quality solution and management of cloud servicing operations in practice [38].

Lei et al. (2021) proposed a method for scheduling and deploying cloud resources that is based on heuristic algorithms and aims to optimize costs. At first, the strategy chooses a deployment plan using the FFD algorithm. Then, based on this, it adopts the greedy method of scheduling migration in order to decide which server type to use to redeploy the virtual machine. In accordance with the experimental outcomes, this strategy has the ability to essentially cut organizational costs whilst planning and implementing cloud resources in a practical way [39].

Shankar et al. (2020) proposed work involves a system that can make interactions in a household significantly more comfortable through the assistance of automation, safety, and the IOT. It enables one to verify and regulate in detail at the location in any section of a house at any distance, or it multi-cloud-protects a house. The principle of the project is a fusion of the multi-cloud and low-energy IC with high-security home automation. The offered solution is reasonably designed to operate the various elements of the intelligent house through the provided fundamentals of the Google Cloud platform [40].

Wan et al. (2020) offered a methodology for evaluating the available resources in the cloud by factoring in the hot/cold startup and shutdown of virtual machines (VMs). After running a cloud computing platform via the M/M/N/oo queuing model, one can accurately obtain performance indicators like cost or elasticity, as well as a cost-to-performance ratio and other metrics. The ideal stopping and cost-performance optimization method considers the following factors while determining the optimal configurations: system service rate, number of hot-starting virtual machines (VMs), start and stop rates for VMs, and cold start and stop rates [41].

Mansouri, Toosi and Buyya (2019) proposed two web-based algorithms that, taking into account both migration and residential costs, make dynamic decisions about which CSP storage classes to use. The initial online algorithm is deterministic, eliminates the need for workload knowledge, and stays within 2γ-1 times the minimum cost achieved by the best offline algorithm. Here, γ is the ratio of the residential cost in the most costly data store to the cheapest one in terms of storage or network costs. The second algorithm is executed online in a random fashion utilizing the "Receding Horizon Control" (RHC) approach and the available future workload data for w time slots. At most, this technique can spend one plus γ/w times the optimal cost [42].

Liu, Pan and Liu (2019) proposed an algorithm for online data tier optimization that does not require consumers to know the frequency of future access. Demonstrate, at least in principle, that data objects stored in a two-tier StaaS cloud may attain assured competitive ratios using the suggested web algorithm. Last but not least, conduct thorough testing to demonstrate the efficacy of suggested web algorithm and its ability to drastically save expenses when contrasted with continuously storing data objects in single tier or constantly shifting data items across tiers based on their access frequencies [43].

Powell, Miura and Munetomo (2018) proposed a method for selecting optimal configurations of cloud resources taking into account of conflicting objectives and user constraints, both soft and hard. The size of solution space and the complexity of the optimization problem determine the optimal order of operation for two distinct but complementary processes that comprise proposed technique. One process generates feasible configurations, while the other selects optimal configurations [44].

Afzal and Kavitha (2018) Reducing workload pressure is the primary emphasis of the suggested research. As part of the load-balancing process, the cloud provider must pay more to move the extra jobs from overburdened to unused servers. Associated with the cloud service provider (CSP), it should be kept low during load balancing. One method that has been proposed to lessen the burden of migration costs is the enhanced modified distribution load balancing [45].

Table II outlines recent research on cost optimization methods to enhance resource use, cut costs, and improve performance in cloud systems. While effective complexity, and scalability limits. Future work aims to extend solutions to hybrid/multi-cloud setups, integrate AI, and enable real-time predictive optimization.

Table 2: Summary of Previous Study on Cost Optimization in CLoud

Reference	**Study On**	**Approach**	**Key Findings**	**Challenges / Limitations**	**Future Directions**
Fé et al. (2022)	Auto-scaling optimization in cloud	SPN modelling + GRASP metaheuristic	Estimates SLA metrics; finds cost-performance trade-offs	Modelling complexity; dynamic scaling	Apply to complex clouds; real-time adaptation
Lei et al. (2021)	optimising the scheduling and deployment of cloud resources to minimise costs	Initial deployment using FFD algorithm; VM deployment with greedy scheduling migration algorithm	Efficient cloud resource planning; significant enterprise cost reduction	Scalability with larger cloud environments	Integrating more dynamic and real-time scheduling
Shankar et al. (2020)	Smart home automation with multi-cloud for security and ease	Multi-cloud design; IoT integration with low energy IC; remote monitoring and control using Google Cloud	Enhanced security and remote accessibility in smart homes	Handling data privacy and multi-cloud interoperability	Expand to other IoT applications; improve security models
Wan et al. (2020)	Cloud resource performance and cost analysis	M/M/N/∞ queuing model; multi-objective optimization for performance and cost; optimal stopping algorithms	Achieved balanced optimization between performance and cost; accurate VM startup/shutdown analysis	Modelling complexity of cloud workloads	Extend model to heterogeneous cloud platforms
Mansouri, Toosi and	Online algorithms for	Deterministic and randomized online	Competitive cost performance close to	Dependence on accurate future	Improve predictive

Buyya (2019)	storage cost and migration trade-offs	algorithms with Receding Horizon Control for storage class selection	offline optimal; dynamic workload adaptability	workload prediction	workload models; reduce computational cost
Liu, Pan and Liu (2019)	Cost optimization for Storage as a Service (StaaS) cloud	Online algorithm for tiered data storage decisions without future access frequency knowledge	Significant cost savings over static tiering or naive transfer policies	Handling unpredictability in access patterns	Extend to multi-tier storage; incorporate machine learning for prediction
Powell et al. (2018)	Optimal cloud resource configuration selection	Separate processes for feasible configuration generation and optimal configuration selection	Flexibility in execution; able to handle complex multi-objective problems	Managing complexity and size of solution space	Develop heuristics for faster selection in large spaces
Afzal et al. (2018)	Task load balancing with low migration cost	Improved Modified Distribution Load Balancing (IMDLB) algorithm	Reduced migration cost while balancing load effectively	Minimizing migration cost without degrading performance	Extend algorithm to heterogeneous CSPs; real-time adaptation

VI. CONCLUSION AND FUTURE WORK

Cost reduction in multi-cloud settings is becoming a crucial component of contemporary cloud strategy, enabling organizations to maximize value while controlling operational and capital expenses. This review analyzed various strategies, including rightsizing and auto-scaling, which ensure that resources align with actual workload requirements, and algorithm-driven approaches like FFD-based virtual machine deployment and greedy server purchasing, which reduce hardware overhead. Migration strategies were also shown to enhance utilization by consolidating workloads, thus lowering energy and maintenance costs. The literature reveals that heuristic algorithms, online optimization methods, and predictive models have delivered notable improvements in cost management across diverse multi-cloud scenarios. However, challenges such as model complexity, scalability limitations, and dependency on workload-specific tuning remain. In order to fully achieve the promise of cost optimization in more dynamic cloud environments, organizations will need to address these concerns.

The creation of AI-powered, real-time decision-making frameworks that can dynamically adjust to changing workloads should be the forefront of future research on optimizing costs across many clouds. Machine learning models capable of predicting demand patterns can be integrated with auto-scaling and resource allocation strategies to further reduce costs. Multi-tier storage optimization and predictive load balancing should be extended to multi-cloud and hybrid environments to ensure efficiency across heterogeneous infrastructures. Furthermore, incorporating blockchain-based cost auditing and transparent billing mechanisms could improve trust and accountability in multi-provider ecosystems. As edge computing becomes more prevalent, optimizing the interplay between cloud and edge resources will also be a vital area for exploration, ensuring balanced performance and cost efficiency.

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