Game Theory–Based Resource Allocation Framework for Efficient and Fair Multi-Tenant Cloud Computing Environments: A Review Study

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ABSTRACT

Cloud computing enables scalable, on-demand access to computing resources, yet efficient resource allocation remains difficult due to dynamic workloads, heterogeneous VM demands, and multi-tenant competition. This study reviews game theory–based approaches for optimizing cloud resource allocation by modelling strategic interactions between cloud service providers and users. It summarizes key mechanisms including Stackelberg games for pricing and hierarchical allocation, non-cooperative games for competitive resource sharing, coalition formation for collaborative utilization, repeated games for long-term behaviour adaptation, and mechanism design for incentive-compatible policies. The paper also outlines a cloud resource management architecture comprising a Register Centre, Cloud Environment Monitor, Infrastructure Management, and Control Centre to support centralized coordination and real-time decision-making. Literature evidence shows that game-theoretic models improve utilization, reduce latency and energy consumption, and enhance fairness across cloud, edge, UAV, IoT, and vehicular environments. However, scalability, interoperability, security integration, and real-world deployment remain open challenges, motivating hybrid game-theory–machine-learning solutions.

Keywords: *Game Theory, Cloud Computing, Resource Allocation, Nash Equilibrium.*

1. Introduction

Cloud computing has transformed modern information technology by enabling scalable, on-demand, and cost-efficient access to computational resources. Organizations increasingly rely on cloud platforms to deploy applications, process data, and manage digital services without investing heavily in physical infrastructure. Despite these advantages, efficient resource allocation remains one of the most challenging problems in cloud environments. The dynamic nature of workloads, heterogeneous virtual machine (VM) requirements, and multi-tenant infrastructures often lead to inefficient utilization of resources when traditional static allocation strategies are applied. Over-provisioning wastes computational capacity and increases operational costs, whereas under-provisioning results in performance degradation and service-level agreement (SLA) violations [1-5]. To address these issues, researchers have explored intelligent resource management frameworks that dynamically allocate computing resources based on real-time conditions. A typical cloud resource management system consists of several interconnected components responsible for monitoring infrastructure, managing virtualized resources, and making allocation decisions. Physical servers register their configurations in a centralized registry, while monitoring modules collect metrics such as CPU usage, memory consumption, and network status. These data are analyzed by a control centre that determines optimal VM placement and scheduling strategies. Infrastructure management modules then implement these decisions by creating, migrating, or terminating virtual machines. Such architectures enable cloud service providers (CSPs) to maintain flexibility and responsiveness in large-scale distributed data centres [6-11]. Game theory has emerged as a powerful mathematical framework for modelling strategic interactions among multiple stakeholders in cloud ecosystems. In a typical cloud environment, CSPs aim to maximize revenue and resource utilization, whereas users seek cost efficiency, performance guarantees, and fairness. Game-theoretic approaches model these conflicting objectives and help design resource allocation strategies that balance individual incentives with system-wide efficiency. For instance, Stackelberg games represent hierarchical decision-making scenarios where CSPs act as leaders by setting prices or resource limits, and users respond by adjusting their demand. Non-cooperative games capture competition among users for limited resources, while coalition formation games explore collaborative strategies that reduce costs through shared resource usage. Repeated game models further allow learning and trust development through long-term interactions. [12-15] Another important area is game-theoretic mechanism design, which focuses on creating incentive-compatible policies such as pricing schemes and allocation algorithms. By aligning the objectives of providers and users, these mechanisms encourage truthful behaviour and efficient resource utilization. Although significant progress has been made, challenges remain in designing scalable solutions capable of handling complex real-world cloud environments with massive data volumes and diverse application requirements. Overall, integrating game theory with intelligent cloud resource management systems offers promising opportunities to enhance fairness, efficiency, and performance. As cloud infrastructures continue to evolve toward large-scale, heterogeneous, and edge-integrated ecosystems, future research will focus on developing adaptive algorithms that combine predictive analytics, distributed decision-making, and game-theoretic optimization to achieve sustainable and reliable cloud computing services [16-19].

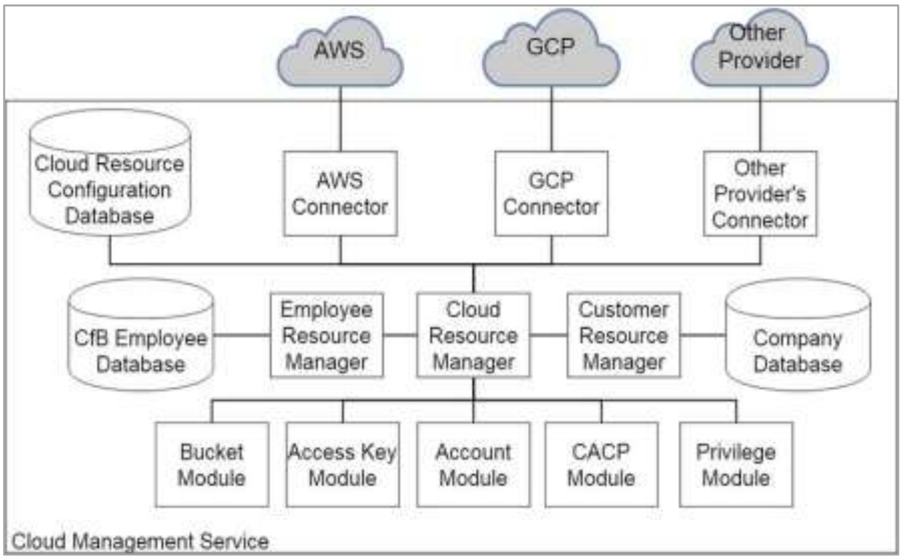

Fig 1: Multi-Cloud Resource Management and Cloud Management Service Architecture

2. Review of Literature

Gillet.al., (2024) Previous studies had reported that cloud computing had become a critical component of modern technology due to its accessibility, scalability, and cost-effectiveness. However, the literature had indicated that security challenges in cloud environments had posed significant concerns, often exceeding the capabilities of traditional security measures. Research had suggested that game theoretic models could provide a valuable framework for addressing these challenges by modeling strategic interactions among multiple parties with conflicting interests. Survey studies had analyzed existing research to investigate the practical application of game theory in enhancing security in cloud computing environments. Findings had shown that game theoretic approaches had the potential to offer effective security solutions, but the literature had also emphasized the need for further research to overcome practical limitations and fully implement these models in real-world cloud computing contexts.

Bezziane et.al., (2024) had indicated that integrating Unmanned Aerial Vehicles (UAVs) into these cloud ecosystems had enabled new applications, including delivery services, disaster response, and surveillance. However, the literature had also highlighted challenges in resource management and service selection due to UAV-specific constraints and variations in service quality. To address these issues, studies had proposed a Game Theory-based UAV-cloud Service Selection Architecture (GT-SSA), which had been designed to optimize decision-making for Client Drones and Provider Drones, thereby enhancing service selection efficiency. Findings had shown that GT-SSA had demonstrated resilience to scalability concerns, as reflected in metrics such as Discovery Delay, Consumption Delay, End-to-End Delay, and energy consumption. Comparisons with the Game Theory approach for Cloud Services in MEC- and UAV-enabled networks (GTCS) had indicated that GT-SSA outperformed GTCS in Successful Execution Rate, Average Execution Time, and energy consumption, while also surpassing fuzzy logic-based methods in service selection efficiency.

Wu et.al., (2023) had reported that the rapid development of Cloud Computing (CC) had led to innovative ecosystems such as Mobile Cloud Computing (MCC). Research had indicated that integrating Unmanned Aerial Vehicles (UAVs) into these cloud ecosystems had enabled new applications, including delivery services, disaster response, and surveillance. However, the literature had also highlighted challenges in resource management and service selection due to UAV-specific constraints and variations in service quality. To address these issues, studies had proposed a Game Theory-based UAV-cloud Service Selection Architecture (GT-SSA), which had been designed to optimize decision-making for Client Drones and Provider Drones, thereby enhancing service selection efficiency. Findings had shown that GT-SSA had demonstrated resilience to scalability concerns, as reflected in metrics such as Discovery Delay, Consumption Delay, End-to-End Delay, and energy consumption. Comparisons with the Game Theory approach for Cloud Services in MEC- and UAV-enabled networks (GTCS) had indicated that GT-SSA outperformed GTCS in Successful Execution Rate, Average Execution Time, and energy consumption, while also surpassing fuzzy logic-based methods in service selection efficiency.

She & Zhao (2023) had reported that the development of intelligent applications had revealed the limitations of relying solely on traditional single-type computing units, which could not efficiently meet diverse cloud computing requirements. Research had indicated that heterogeneous computing, employing multiple types of processing units such as Graphics Processing Units (GPUs) and Field Programmable Gate Arrays (FPGAs), could better adapt to the needs of these applications. However, the literature had also highlighted that trade-offs between profit and costs in scheduling heterogeneous computing resources required careful attention. To address these challenges, studies had established heterogeneous computing resource scheduling models based on Stackelberg differential games, involving Computing Power Trading Platforms (CPTPs), Heterogeneous Computing Service Providers (HCSPs), and Heterogeneous Computing Application Providers (HCAPs). Findings had suggested that utility maximization for CPTPs and HCSPs, subject to rental ratios, pricing strategies, and energy consumption, could achieve a Stackelberg Nash Equilibrium solution. Furthermore, researchers had proposed Support Vector Machine models based on Artificial Fish (SVM-AF) to predict application access times, and had applied distributed iteration methods and Cauchy distribution to optimize pricing strategies, improve convergence, enhance user computing revenue, and reduce energy consumption during resource scheduling.

Kengne Tchendji et.al., (2023) had addressed the challenge of resource allocation in virtual network environments, focusing on Infrastructure Providers (InPs) and Service Providers (SPs). The literature had reported that, in such environments, resources such as storage space, bandwidth, and CPU could be reallocated flexibly among users, particularly in the context of cloud services. However, because these resources originated from physical networks, their allocation had been constrained. Researchers had noted that service providers frequently had to manage multiple parameters—use duration, price, availability, fidelity—which often resulted in unfair or suboptimal allocation schemes. Several studies had proposed game theory-based solutions allowing physical infrastructure providers to assign resources to service providers. Unlike earlier literature that had considered only a single type of resource, these studies had addressed multiple resources, including storage space, bandwidth, RAM, and processors. Simulation results had indicated that such approaches optimized resource utilization and improved service quality compared to previous methods reported in the literature.

Wu et.al., (2023) Previous studies had reported that, with the widespread adoption of 5G and the Internet of Things (IoT), edge computing and cloud computing had been used collaboratively for task offloading and processing. Research had indicated that, although massive numbers of devices such as smartphones were organized into multi-cell networks, most existing works had not considered computation offloading under inter-cell interference, which had often led to overestimated transmission rates and inappropriate offloading decisions. To address this challenge, studies had proposed COMEC, a Computation Offloading scheme in multi-cell networks with edge-cloud collaboration, designed to minimize total costs in terms of delay and energy consumption. Researchers had formulated COMEC as an optimization problem accounting for inter-cell interference and, recognizing that users' offloading decisions were interdependent, had modeled it as a non-cooperative game. Findings had shown that the game constituted a general ordinal potential game with a pure strategy Nash equilibrium, and that algorithms based on the finite improvement property could achieve this equilibrium. Simulation results had suggested that COMEC outperformed other baseline schemes in overall system cost.

Agbaje et al. (2022) stated that cloud computing was a groundbreaking technique that provided a whole lot of facilities such as storage, memory, and CPU, as well as facilities such as servers and web service. They mentioned that it allowed businesses and individuals to subcontract their computing needs as well as trust a network provider with their data warehousing and processing. The fact remained that cloud computing was a resource-finite domain where cloud users contended for available resources to carry out desired tasks. They pointed out that resource management (RM) was a process that dealt with the procurement and release of resources. They added that the management of cloud resources was desirable for improved usage and service delivery. In their paper, they reviewed various resource management techniques embraced in literature. They concentrated majorly on investigating game-theoretic submission for the management of required resources, as a potential solution in Modelling the resource allocation, scheduling, provisioning, and load balancing problems in cloud computing. They presented a survey of several game-theoretic techniques implemented in cloud computing resource management. Based on this survey, they presented a guideline to aid the adoption and utilization of a game-theoretic resource management strategy.

Wang et al. (2022) discussed that task offloading and resource allocation were the major elements of edge computing. They mentioned that a reasonable task offloading strategy and resource allocation scheme could reduce task processing time and save system energy consumption. They noted that most of the current studies on the task migration of edge computing only considered the resource allocation between terminals and edge servers, ignoring the huge computing resources in the cloud center. They proposed a coarse-grained task offloading strategy and intelligent resource matching scheme under Cloud-Edge collaboration to sufficiently utilize the cloud and edge server resources. They considered the heterogeneity of mobile devices and inter-channel interference and established the task offloading decision of multiple end-users as a game-theory-based task migration model with the objective of maximizing system utility. Additionally, they proposed an improved game-theory-based particle swarm optimization algorithm to obtain task offloading strategies. They stated that experimental results showed that the proposed scheme outperformed other schemes with respect to latency and energy consumption and scaled well with increases in the number of mobile devices.

Jiang et al. (2021) stated that with the development of the vehicular network (VN), emerging driver assistance applications were adhibited in daily life. They mentioned that commonly, edge computing was adopted to satisfy the timeliness requirements of these applications, as the vehicular devices were usually insufficient in computation resources. They noted that the increasing volume of service requests (SRs) was potentially overloading the edge servers (ESs), thus increasing the task execution time. They added that the randomness and the diversity of the SRs also challenged the dynamic resource allocation for the users. To deal with these challenges, they proposed a task offloading and resource allocation scheme based on game theory and reinforcement learning (RL) named TORA. They mentioned that game theory was leveraged to determine the optimal task offloading strategy for improving the quality of service (QoS) and RL was applied to implement the dynamic resource allocation of the ES. They concluded by stating that the robust performance of the proposed method was validated by comparative experiments.

Liu et al. (2020) highlighted that with the rapid cloud technological advancement and economic growth, more and more organizations had purchased cloud resources for daily business operations besides building their own IT infrastructures. They mentioned that it was very important to understand the economy of cloud computing. They focused on examining the private idle computing resources owned by various organizations who were willing to form a network of ad hoc cloud provider and sell the services to cloud users. In such a case, the organizations could not only meet their own demands but also sell their idle computing resources in the form of ad hoc cloud. They noted that the organizations, as providers, aimed at maximizing their own profit through adjusting business costs and sale prices. Due to the uncertainty of the amount of idle computing resources, dynamic pricing was challenging. They approached the problem from the perspective of game theory and formulated it as a non-cooperative game among multiple organizations, i.e., the game player. They mentioned that for each player, a utility function was used to represent its profits. They concluded by stating that this paper had proved that there exists Nash equilibrium for this game problem and they proposed an iterative proximal algorithm (IPA) for calculating the Nash equilibrium.

Emami Khansari & Sharifian (2020) observed that the Internet of Things (IoT) was rapidly gaining popularity as a result of the advancements in portable embedded devices and wireless protocols, enabling a new class of services. They mentioned that edge clouds provided IoT services as a new paradigm called fog computing. They noted that as the number of available IoT devices increased, more efficient methods were required to select the optimal combination of services out of several existing candidates in edge clouds while composing more complex IoT workflow tasks. They proposed a cloud-based platform for management of IoT service selection and composition in fog computing to enhance QoS parameters such as bandwidth usage, latency, and distributed resource utilization. In particular, they proposed a multi-objective evolutionary game theory, enhanced by evaporation-based water cycle algorithm (EG-ERWCA) to optimize CPU usage, power consumption, and latency of the IoT workflows in cloud-assisted fog computing environments. They mentioned that many different real IoT workflows were used for evaluation of the proposed method in comparison with the state-of-art algorithms and simulation results showed that the overall quality of service was improved by 2.66 times compared to rival algorithms.

Patra et al. (2019) noted that cloud computing was one of the emerging technologies in the field of distributed computing and was designed as per the requirement and demand of the user. They mentioned that it used the virtualization technique to create multiple virtual machines that were the basis of computation in the cloud. They highlighted that one of the major issues in cloud computing was to efficiently schedule the tasks and completing their execution before the deadline to maximize the utilization of the processor, maximize the throughput, and reduce the waiting time of the task. They proposed a system model and a game-theoretic framework for scheduling real-time tasks in the cloud computing environment to reduce the total completion time and total waiting time. They mentioned that in their game model, task acted as a player, the virtual machine acted as a strategy, and the payoff of the player was represented by completion time and waiting time. They performed experiments using the non-cooperative and cooperative game model and their experimental results showed that the total execution time and total waiting time were less in the cooperative game model than a non-cooperative game model.

Ficco et al. (2018) pointed out that elasticity was a key feature in cloud computing, which distinguished this paradigm from other ones, such as cluster and grid computing. They mentioned that dynamic resource reallocation was one of the most important and complex issues in cloud scenarios, which could be expressed as a multi-objective optimization problem with the opposing objectives of maximizing demand satisfaction and minimizing costs and resource consumptions. They proposed a meta-heuristic approach for cloud resource allocation based on the bio-inspired coral-reefs optimization paradigm to model cloud elasticity in a cloud-data center, and on the classic Game Theory to optimize the resource reallocation schema with respect to cloud provider's optimization objectives, as well as customer requirements, expressed through Service Level Agreements formalized by using a fuzzy linguistic method.

Mohanty et al. (2018) stated that the availability of high-capacity networks, low-cost computers, storage devices, as well as the widespread adoption of hardware virtualization, service-oriented architecture, and autonomic and utility computing had led to growth in cloud computing. They also mentioned that in that era of cloud-based services, all intelligent transportation systems were connected to improve transportation safety and enhance the comfort of driving. They further added that the vision of all vehicles connected posed a significant challenge to the collection and storage of large amounts of traffic-related data. They proposed to integrate cloud computing and vehicular networks in such a way that the vehicles could share computation resources, storage resources, and bandwidth resources. The proposed architecture included a vehicular cloud, a roadside cloud, and a central cloud. They presented a game-theoretical approach to optimally allocate cloud resources and solved virtual machine migration due to vehicle mobility based on a resource reservation scheme.

Shyam & Chandrakar (2018) mentioned that the aim of cloud computing was to provide utility-based IT services by interconnecting a huge number of computers through a real-time communication network such as the Internet. They observed that since many organizations were using cloud computing which were working in various fields, its popularity was growing. They noted that because of this popularity, there had been a significant increase in the consumption of resources by different data centers which were using cloud applications. They discussed on the optimization of resource allocation so as to provide cost benefits to the Cloud service users and Cloud service providers.

Yuan et al. (2017) pointed out that Geo-distributed Datacenter Cloud was an effective solution to store, process, and transfer the big data produced by Internet-of-Things (IoT). They mentioned that a key challenge in that distributed system was how to allocate the bandwidth resources among these geo-distributed datacenters of this cloud efficiently. They aimed to address this challenge by optimizing the transfer bandwidth resources among different geo-distributed datacentres. To that end, they firstly analyzed the interaction between the traffic of physical networks and the data flow of Geo-distributed Datacenter Clouds, and then established a game theory-based model for cloud resource allocation. Based on this model, they proposed a dynamic resource allocation strategy and its corresponding algorithm that were adaptable to the Internet conditions. They claimed that since the background traffic, capacity limit of physical networks as well as the flows and resource demands of geo-distributed datacenters were taken into account, this new strategy could achieve the load balance of the physical networks and content transferring among different geo-distributed datacentres effectively. They also mentioned that the real-world trace data was adopted to validate the effectiveness and efficiency of the proposed resource allocation strategy. They further added that compared with existing strategies, the evaluation results demonstrated that their proposed strategy could balance the workloads of physical networks, reduce the response delay of cloud applications, and possess an excellent adaptability.

Zhang & Zhu (2017) discussed that Mobile cloud-computing was a wireless network environment that focused on sharing the publicly available wireless resources. They emphasized that wireless network virtualization provided an efficient technique to implement the mobile cloud-computing by enabling multiple virtual wireless networks to be mapped onto one physical substrate wireless network. They stated that one of the most important challenges of this technique lay in how to efficiently allocate the wireless resources of physical wireless networks to the multiple virtual wireless network users. To overcome these difficulties, they proposed a set of novel game-theory based schemes to resolve the wireless resources allocation problem in terms of transmit power and wireless spectrum. They formulated these wireless resources allocation problem as the gaming process where each mobile user bid for the limited wireless resources from physical substrate wireless networks and competed with the other mobile-user players bidding for the same resources. They claimed that under their proposed game-theory framework, they developed three types of wireless resources request strategies: price-based strategy, correlation-based strategy, and water-filling-based strategy to allocate wireless resources under three different gaming mechanisms. They mentioned that the extensive simulation results obtained validated and evaluated their proposed schemes.

Godhrawala & Sridaran (2016) noted that Cloud was an environment which provided services and resources to enterprises on the go. They mentioned that it provided various resources like CPU, Memory, Storage, Network Bandwidth, most importantly some service to the subscriber. They added that Cloud allowed many users to use central facilities, thus posing the problem of resource allocation between various users. They stated that allocation of the resource was to be done on demand; moreover, it must be done in a fair manner so that no user was denied a service. They further mentioned that optimization of resource allocation was needed so that costs could be reduced and profits could be increased. They surveyed various methods to allocate resource amongst users.

Jebalia et al. (2015) declared that in their paper, they had dealt with the resource allocation problem in cloud computing environments where users competed to have enough resources to run their applications and store their data. They stated that they had presented an overview of the resource allocation models adopted in literature and focused essentially on game theoretic approaches. They mentioned that to this purpose, a set of criteria had been defined so as to assess the performance of the proposed game models with respect to cloud computing needs in terms of QoS and security. They further added that at the end of their paper, they had formalized and discussed an optimization model for resource allocation based on a cooperative game approach where cloud providers may have formed a pool of resources in order to maximize their profit. They especially focused on providing a model that compensated losses generated by the adoption of security mechanisms and maximized the overall payoff.

Jebalia et al. (2013) stated that Cloud Computing was a revolutionary model that offered everything as a service (storage, servers, network, etc.). They mentioned that it enabled users to outsource their data and entrust a service provider with its storage and processing. They added that however, they had been dealing with a resource-limited environment where users competed to have enough resources for their tasks. They declared that thus, a resource allocation model was needed for a better utilization of shared resources. They mentioned that in their paper, they had presented an overview of the resource allocation models adopted in literature and had focused essentially on game theoretic approaches for resource allocation. They added that a comparative study was given at the end of their paper. They stated that to this purpose, a set of criteria had been defined so as to assess the performance of the proposed game models with respect to cloud computing needs.

Lu et al. (2012) mentioned that Cloud federation had been proposed as a new paradigm that allowed providers to avoid the limitation of owning only restricted amounts of resources. They claimed that multiple cloud providers could cooperate to establish a cloud federation to support both internal users and public cloud users. They stated that federation enhanced providers' ability to serve for public cloud users and as a result of cooperation, cloud providers in federation could gain more profit. They emphasized that there was a need to develop a way that how cloud providers could form a federation and how to solve the problem of resource and revenue sharing. They declared that in their paper, they studied the cooperative behaviour of multiple cloud providers with different resources. They proposed a game theoretic policy that helped cloud providers in the decision-making process to form coalitions to increase resource utilization and profit. They mentioned that they also presented the simple model of resource and revenue sharing with coalition formation and developed the cloud provider and coalition's cooperative utility forms. They stated that to obtain the solution, they developed the stochastic linear programming game model which took the uncertainty of internal users from each provider into account. They added that based on coalitional game they analysed the stability of the coalition formation among cloud providers and that the simulation results indicated that the game theoretic coalition could lead to better computing resource utilization and higher profit.

2.1 Systematic Reviews and Research Gaps

Author (Year)	Key Research	Methodology	Research Gaps	Findings
Agbaje et al. (2022)	Game-theoretic resource management in cloud	Survey, guideline	Integration, dynamic adaptation	Guidelines for adopting game-theoretic resource management.
Wang et al. (2022)	Task offloading and resource allocation in edge	Game theory, optimization	Dynamic allocation, heterogeneity	Efficient task offloading scheme with improved latency and energy consumption.

Jiang et al. (2021)	Task offloading and resource allocation in vehicular networks	Game theory, RL	Dynamic adaptation, security	TORA scheme for optimal task offloading and resource allocation, validated experimentally.
Liu et al. (2020)	Resource allocation among organizations forming ad hoc clouds	Non-cooperative game	Dynamic pricing, scalability	Nash equilibrium finding with iterative proximal algorithm, addressing uncertainty in resource availability.
Emami Khansari & Sharifian (2020)	IoT service selection and composition in fog computing	Multi-objective evolutionary game theory	Real-time adaptation, security	EG-ERWCA approach for optimizing IoT workflows, improving QoS parameters.
Patra et al. (2019)	Game-theoretic task scheduling in cloud computing	Non-cooperative and cooperative games	Real-time adaptation, scalability	Cooperative game model minimizes total execution and waiting time, compared to non-cooperative model.
Shyam & Chandrakar (2018)	Optimization of resource allocation in cloud computing	Survey, optimization	Cost efficiency, interoperability	Focus on cost benefits for users and providers, lacking interoperability solutions.
Godhrawala & Sridaran (2016)	Fair resource allocation in cloud environments	Survey, fairness criteria	Optimization, fairness criteria	Surveyed methods, highlighted need for fair resource allocation and optimization techniques.
Ficco et al. (2018)	Elastic resource allocation in cloud-data centers	Coral-reefs optimization, game theory	Elasticity, cost optimization	Coral-reefs optimization model for dynamic resource reallocation, considering customer requirements and provider objectives.
Mohanty et al. (2018)	Integration of cloud computing and vehicular networks	Game theory, resource reservation	Integration challenges, scalability	Game-theoretical approach for optimal cloud resource allocation and virtual machine migration in vehicular networks.
Yuan et al. (2017)	Bandwidth resource allocation in geo-distributed datacenter clouds	Game theory, dynamic allocation	Bandwidth optimization, real-world validation	Dynamic allocation strategy balancing workloads and reducing response delay, validated with real-world data.
Zhang & Zhu (2017)	Wireless resource allocation in mobile cloud computing	Game theory, wireless network virtualization	Efficiency, scalability	Proposed game-theory based schemes for efficient wireless resource allocation, lacked scalability evaluation.
Jebalia et al. (2015)	Resource allocation optimization in cloud computing	Game theory, cooperative game model	QoS optimization, scalability	Proposed optimization model based on cooperative game theory for maximizing profit and addressing security concerns.

Jebalia et al. (2013)	Resource allocation models in cloud computing	Game theory, comparative study	Dynamic adaptation, security	Overview of resource allocation models, comparative study lacking focus on dynamic adaptation.
Lu et al. (2012)	Cooperative behaviour of cloud providers in federation	Stochastic linear programming, coalition formation	Resource sharing, revenue optimization	Game-theoretic policy for cloud provider cooperation, simulation indicating increased profit and resource utilization.

3. Conclusion

Game theory–based approaches provide an effective framework for optimizing resource allocation in cloud computing environments characterized by dynamic workloads, heterogeneous resources, and multi-tenant competition. Through modeling strategic interactions between cloud service providers and users, these approaches balance economic incentives with system-level efficiency. Stackelberg games support hierarchical pricing and demand management, non-cooperative games enable fair competition for limited resources, and cooperative or coalition games enhance shared utilization and profitability. Repeated and evolutionary games further allow adaptive behaviour in long-term cloud interactions. The reviewed literature demonstrates that game-theoretic models improve resource utilization, reduce latency and energy consumption, and enhance fairness across cloud, edge, IoT, UAV, and vehicular computing environments. However, challenges remain in scalability, interoperability, security integration, and real-world implementation.

Future research should emphasize hybrid models combining game theory with machine learning, distributed optimization, and real-time analytics. Such integration can enable intelligent, autonomous, and sustainable cloud resource management. Overall, game theory offers a robust and strategic foundation for designing efficient and incentive-compatible resource allocation mechanisms in next-generation cloud ecosystems.

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