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Evolution of Cloud Computing: Milestones, Innovations, and Adoption Trends

Abhishek Sapkal[1*], Leoson Heisnam[2], Satya Sri Kusi[3]

Under graduate, Bachelor of computer application, Amravati University, Akola, Maharashtra[1]
Visiting Faculty, Department of Cyber Security and Digital Forensics, Institute of Forensic Sciences for Training & Skilling, National Forensic Science University, Manipur[2]
Assistant professor, Department of Forensic science, Mohan Babu University, Andhra Pradesh[3]

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Abstract

Cloud computing is a method of delivering IT services through a network of interconnected servers, forming a unified system known as the "Cloud." This virtualized ecosystem integrates interconnected networks, servers, applications, storage, and services, enabling users to conveniently access them as needed with minimal administrative intervention. This review article focuses on virtualization and containerization as foundational pillars, the paper explores their revolutionary impact on resource management and deployment efficiency. It further delves into the impending trends and challenges set to shape the cloud computing landscape from 2025 to 2030. It reviews the anticipated adoption of hybrid and multi-cloud strategies, offering organizations tailored solutions while mitigating risks of vendor lock-in. The rise of edge computing is highlighted as a pivotal solution to address latency issues and foster a competitive IoT ecosystem. Additionally, integration of AI and machine learning within cloud frameworks is poised to unlock new realms of innovation and optimization, propelling digital transformation forward. The article underscores the imperative for enhanced security measures to safeguard sensitive data and ensure user privacy. Ongoing price competitions among cloud providers and increased regulatory scrutiny are also discussed, highlighting the dynamic landscape of cloud computing. It provides valuable insights into the past, present, and future trajectory of cloud computing. It concludes by affirming the pivotal role of cloud computing in driving digital innovation and empowering organizations to thrive in an increasingly interconnected world, offering recommendations for businesses to leverage emerging technologies and navigate evolving challenges effectively.

Keywords: Cloud computing, Hybrid and multi-cloud strategies, IoT ecosystem, AI and machine learning integration, Security measures etc.

1. Introduction

Cloud computing denotes the utilization of numerous server machines through a digital network, operating cohesively as an integrated system. The "Cloud" is a virtualized environment comprising networks, servers, applications, storage, and services, accessible to users on-demand with minimal management involvement. It offers resources and services without requiring users to have in-depth system knowledge, providing a wide range of applications and scalable services tailored to users and businesses [1]. Cloud computing is a computing technique that delivers IT services through interconnected low-cost computing units via IP networks. Emerging from search engine platform architecture, it possesses five pivotal technical traits: expansive resource capacity, exceptional scalability, shared resource pools encompassing both virtual and physical assets, dynamic resource allocation, and versatile applicability across various purposes [2]. Cloud computing gives services to users, allowing them to store and process data without needing hardware. It's a delivery model for computing services that facilitates the real-time development of various services. Examples include Google Accounts and Amazon Elastic Compute Cloud (EC2).

Table-1: Types of cloud computing services [3], [4], [5].

Cloud Type	Description
1. Public Cloud	Provides open access to services over the internet, managed by dedicated service providers.
Infrastructure as a Service (IaaS)	This generally offers network, storage, and software systems, replacing traditional data center functions.
Platform as a Service (PaaS)	This generally provides virtualized servers for application development and deployment, minimizing server maintenance.

- Software as a Service (SaaS)	Delivers software applications through a web browser, eliminating the need for installation.
2. Private Cloud	Used by businesses for enhanced data security and control. Can be on-premise or externally hosted.
- On-premise Private Cloud	Cloud infrastructure hosted within the organization's data center.
- Externally Hosted Private Cloud	Cloud infrastructure hosted externally by a cloud service provider.
3. Hybrid Cloud	It generally combines the features of private & public clouds, allowing users to leverage advantages of both.
4. Community Cloud	Shares infrastructure among multiple organizations with common privacy, security, and regulatory needs. Situated between public and private clouds, it provides exclusive resources for two or more organizations with shared considerations.
5. Multi-cloud Computing	Utilizes multiple cloud networks and services simultaneously to address various issues in cloud computing. Users or businesses leverage different cloud services for different applications, enhancing flexibility and resilience.
6. Distributed Cloud Model	A multitude of micro datacenters linked together via medium to high bandwidth connections, administered as a unified entity. Particularly advantageous for private enterprise cloud setups, especially for smaller-scale operations in contrast to extensive public datacenters.

The Internet's expansion drove Internet service providers to adopt cost-effective commodity PCs for storage and computing, sparking the emergence of three primary cloud computing styles: Amazon, Google, and Microsoft. Amazon pioneered Infrastructure as a Service (IaaS) through server virtualization, offering services like Elastic Compute Cloud. Simple Storage Service, and Simple DB. Google focused on a technique-specific sandbox, launching Google App Engine as a Platform as a Service (PaaS) solution in 2008. Microsoft Azure, launched in October 2008, utilizes the Windows Azure Hypervisor and .NET, providing services like Blob Object Storage and SQL Service[6].

including its progression, current status, technological advancements, future directions, challenges, and practical examples. This delves into the origins, current landscape, architectural models, technological innovations, and specific applications within various industries. Through this analysis, this article aims to provide a deeper understanding of cloud computing's evolution, its potential future developments, and its practical implications for businesses and individuals.

2. Present State of Cloud Computing

In the year 2024, the contemporary landscape of information technology is significantly dependent on cloud computing, serving as the foundational framework for diverse operational functions. According to Gartner, an anticipated 95% of emerging workloads are expected to be hosted in the cloud by 2025. Businesses are compelled to adjust their strategies to leverage the adaptability and cost-effectiveness inherent in cloud infrastructure to maintain competitiveness. Projections indicate that global expenditures on cloud services infrastructure will exceed $1 trillion in 2024, driven by various prevailing trends, such as the increased demand for innovative platforms and as-a-service solutions, particularly those incorporating artificial intelligence [7]. Enterprises are increasingly recognizing the cloud not merely as a means of cost reduction but also as a strategic tool for fostering innovation, enhancing agility, and achieving success across diverse industries. The trajectory of cloud computing trends is influenced by rising cloud costs and the growing utilization of advanced AI, including technologies like ChatGPT. Companies are proactively shifting their activities to cloud-based platforms, aiming to optimize efficiency and enhance customer interactions. Organizations will persist in leveraging cloud services to access cutting-edge technologies, thereby improving the overall efficiency of their operations. Cloud computing facilitates the accessibility of new technologies by eliminating the need for building or acquiring expensive infrastructure, crucial for supporting these resource-intensive processes [8].

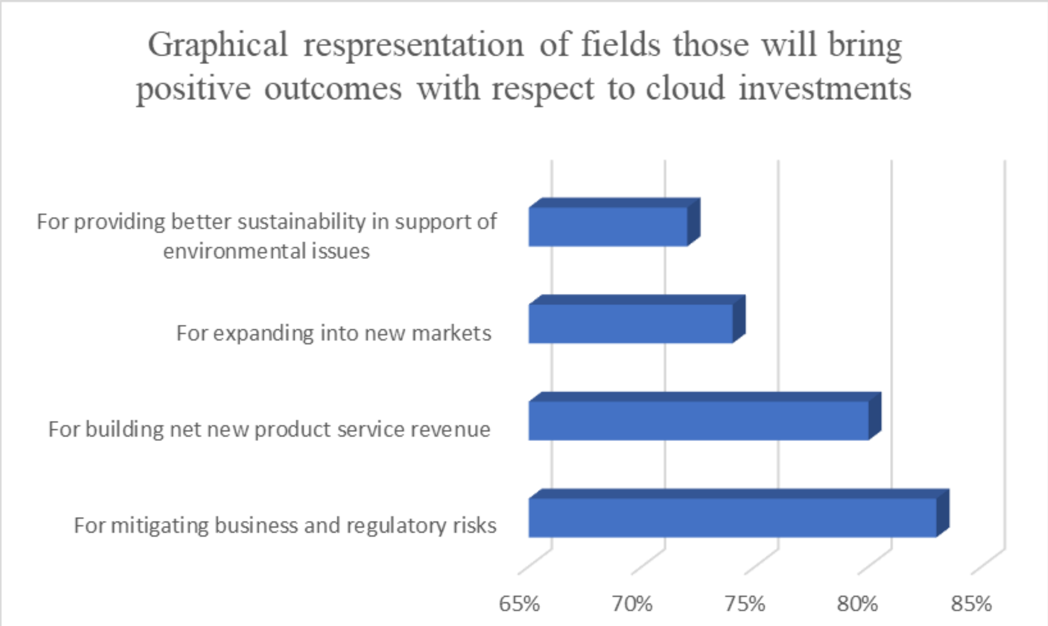

Figure-1: Graphical representation of fields those will bring positive outcomes with respect to cloud investments [7]

The Deloitte US Future of Cloud survey report reveals compelling insights into the favorable outcomes expected from investments in cloud computing across various business domains. A significant 83% of respondents highlight the potential of cloud computing to effectively mitigate business and regulatory risks. Moreover, a substantial 80% express confidence in the capability of cloud investments to generate net new product service revenue. The survey also emphasizes the role of cloud computing in facilitating business expansion, with 74% recognizing its potential for entering new markets. Additionally, 72% of participants acknowledge the positive impact of cloud investments in fostering better sustainability practices, aligning with environmental concerns. These findings underscore the multifaceted benefits that organizations anticipate from embracing cloud technologies, ranging from risk mitigation and revenue generation to market expansion and enhanced sustainability efforts.

Table-2: Recent Emerging Technologies and Practices in the field of Cloud Computing [9]

Cloud Computing Trends for 2024	Description
1. Citizen Developer	The concept of Citizen Developer allows non-coders to connect systems using tools like If This Then That. Expect tools from Microsoft, AWS, Google, etc., for easy app development with a drag-and-drop interface [10].
2. Better AI/ML	AWS and Google are heavily invested in machine learning. Expect advancements in AI/ML integrations, such as AWS DeepLens and Google Lens, with a focus on machine learning-based products. IBM is a leader in AI and machine learning initiatives [11], [12].
3. Automation	Automation is the key to Cloud efficiency. With investments in citizen developer tools and AI, more devices are expected to be released to make automation easier for cloud vendors [13], [14].
4. Continued Investment in Data	Storing data in extensive databases within a distributed computing setting. The widespread utilization of GPUs for data processing will drive the necessity for novel computer architectures. Organizations will execute algorithms concurrently across clusters to facilitate real-time analyses [9].
5. Competition	Increasing competition between AWS, Microsoft Azure, and Google Cloud Platform in pricing, reliability, and against other vendors. Expect a shift towards pay-as-you-use models across all services [15].
6. Kubernetes and Docker to Manage Cloud Deployment	Kubernetes and Docker are poised to revolutionize developers' approach to overseeing cloud deployments, streamlining the process of deploying, scaling, and managing containerized applications through automation [16].

7. Cloud Security and Resilience	Cloud service providers are making substantial investments in security and resilience capabilities, such as data encryption, access management, and disaster recovery measures, to safeguard customer data [17].
8. Multi and Hybrid Cloud Solutions	Businesses are adopting multi-cloud and hybrid cloud solutions to spread workloads across multiple providers while maintaining control over data and applications [18], [19], [20].
9. Cloud Cost Optimization	Cloud providers are developing tools and services to help users manage costs, including cost monitoring, budgeting tools, instance sizing recommendations, and reserved instance options[21], [22].
10. Edge Computing	A developing trend is shifting computational tasks and data storage nearer to devices, thereby reducing latency and bandwidth demands, resulting in expedited and more effective data processing [23], [24].
11. Disaster Recovery	A vital aspect for businesses moving operations to the cloud. Cloud providers are developing solutions for quick recovery from disruptions like natural disasters or cyberattacks[25], [26].
12. Innovation and Consolidation in Cloud Gaming	Cloud providers are investing in cloud gaming, with consolidation happening as major players acquire smaller companies to expand offerings and reach[27], [28], [29]
13. Serverless Computing	A burgeoning trend enables developers to execute code without the burden of server management, thereby lowering infrastructure expenses and enhancing scalability. [30], [31], [32], [33].
14. Blockchain	Integration of blockchain with cloud computing to create new applications and services. Cloud providers offer blockchain-as-a-service (BaaS) solutions for building and deploying blockchain applications[34], [35], [36].
15. IoT	Cloud service providers are allocating resources to develop Internet of Things (IoT) solutions, aimed at assisting businesses in the management and processing of data generated by IoT devices [37], [38].
16. Open-Source Cloud	Growing popularity of open-source cloud solutions for more flexibility and control over cloud infrastructure, offering customization options and lower costs [39], [40].
17. Low-Code and No-Code Cloud Services	Enabling businesses to develop applications and services without deep technical expertise, speeding up development times and reducing costs[41], [42], [43], [44].
18. Cloud-Native Applications	Applications have been designed to run on cloud infrastructure, taking advantage of cloud services. Cloud providers offer tools and services for building and deploying cloud-native applications[45], [46], [47], [48].
19. DevSecOps	An approach integrating security into the software development process. Cloud providers offer tools and services to help businesses implement DevSecOps practices[49], [50], [51].
20. Service Mesh	Advanced technology offers a network of microservices equipped with functionalities such as load balancing, traffic control, and security. Cloud service providers supply service mesh solutions tailored for the management of microservices [52], [53].
21. Increased Focus on Green Computing Initiatives	Cloud providers invest in green computing initiatives, such as renewable energy and energy-efficient infrastructure, to reduce their carbon footprint and meet sustainability goals [54], [55], [56].

3. Virtualization And Containerization in Cloud Computing

3.1. Virtualization

Virtualization serves as the fundamental element of cloud computing. Through virtualization, cloud computing delivers advantages in terms of convenience and efficiency [57], [58]. Virtualization fundamentally involves creating a virtual representation or "version" of entities like servers, operating systems, storage devices, or network resources, enabling their simultaneous utilization across multiple machines. The primary objective of virtualization is to optimize workload management by transitioning conventional computing methods to achieve greater scalability, efficiency, and cost-effectiveness. Virtualization finds application in diverse domains including operating system virtualization, hardware-level virtualization, and server virtualization. This technology, characterized by hardware efficiency, cost reduction, and energy conservation, is swiftly reshaping the foundational principles of computing.[59].

Software-based virtualization mechanisms used in cloud computing include virtualization software that separates a real calculating unit into several virtual ones, allowing for easy allocation and management of computing resources[60]. LightIOV represents an innovative software-driven NVMe virtualization approach, delivering exceptional performance and scalability while conserving precious CPU resources and operating independently of specific hardware requirements. [61]. Hypervisors, which are software that create and run virtual machines (VMs), play an important role in virtualization by allowing the host computer to support multiple guest VMs and preventing interference between them. QEMU is an open-source emulator and virtualizer used for virtualization [62].

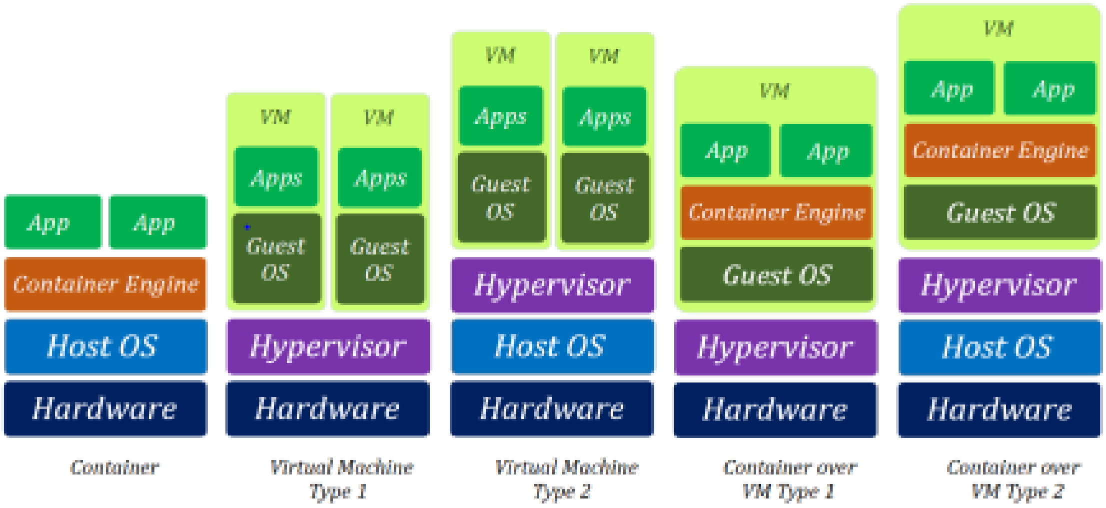

Figure 2: Containerization Setup with Virtual Machines[63]

Virtualization can be implemented at various levels within a computing environment, each offering different levels of abstraction and isolation.

Docker and Kubernetes are popular platforms for container management and orchestration.

Virtualization brings great challenges in the field of data security and privacy protection. For example, it may bind different tenants' virtual resources to the same physical resource, then the user data will be accessed by other users [57].

3.2. Containerization

Containerization is a method used for the agile virtualization of software programs within cloud computing environments. It exerts a beneficial influence on both the development and deployment phases of software. Containers can be categorized into two distinct groups according to their configuration: Application Containers and System Containers [64]. Containers enhance the efficacy of application deployment and find extensive application in both cloud computing and high-performance computing (HPC) settings. By encapsulating intricate programs alongside their dependencies, containers render applications more adaptable and transportable. Nevertheless, HPC environments demand heightened security measures compared to cloud systems, necessitating the inclusion of extensive libraries within HPC containers, thereby impacting their portability. Conversely, cloud containers possess a smaller footprint and exhibit greater portability. Moreover, cloud systems typically integrate advanced container orchestration mechanisms, while HPC systems encounter obstacles in facilitating container orchestration [65] .

Kubernetes stands out as a widely embraced managing platform designed to oversee containerized workloads and services. It facilitates multi-tenancy and offers features such as resource quotas through the Resource Quota API object, enabling effective resource allocation management and ensuring optimal utilization of computational resources [66].

Table-3: Difference between Virtualization and Containerization [67]

Features	Virtualization	Containerization
Security	Offers comprehensive isolation from the host operating system and other virtual machines	Typically offers lightweight isolation from the host and other containers, albeit with a less robust security boundary compared to virtual machines
Guest Compatibility	Supports running various operating system versions within the virtual machine	Operates on the same operating system version as the host
Deployment	Utilizes Hypervisor software to deploy individual virtual machines	Employs Docker for deploying individual containers or utilizes an orchestrator like Kubernetes for managing multiple containers
Persistent Storage	Utilizes technologies such as Virtual Hard Disk (VHD) or Server Message Block (SMB) for shared storage	Relies on local disks for storage within a single node or leverages SMB for shared storage across multiple nodes or servers
Networking	Utilizes virtual network adapters for communication	Implements isolated virtual network adapters, offering slightly reduced levels of virtualization

[68], [69] A novel approach was proposed for dynamically allocating resources in cloud environments using virtualization. This method leveraged the "skewness" strategy to analyze resource utilization across servers, dynamically assigning resources to optimize workloads and implement energy-efficient computing algorithms. Similarly, in [70] the objective was to diminish energy consumption and enhance resource utilization within data centers by employing the Energy-Efficient VM allocation technique with the Interior Search Algorithm (EE-ISA) method, resulting in notable energy conservation.

[71] addressed the decision-making process for shutting down or starting up physical machines (PMs) in cloud environments. They introduced the Energy Conserving Resource Allocation algorithm (ECRASP) algorithm, focusing on conserving power consumption of PMs. In a related study, [72] aimed to optimize the allocation of virtual machines (VMs) in cloud environments using the HABBP algorithm, outperforming traditional binding policies in terms of job execution time.

Load balancing within cloud computing was a common focus among several studies. [73] introduced a Round-Robin scheduling algorithm aimed at diminishing average waiting and turnaround times for processes. Similarly, [74] presented the Dynamic and Elastic Ant Colony Optimization Load Balancing (DEACOLB) algorithm with the goal of minimizing the average Make Span and reducing standard deviations.

[75] explored the influence of virtualization on energy consumption in cloud computing. They conducted a comparative analysis between scenarios employing the Power Saver Scheduler Algorithm (PSSA) and green algorithms, underscoring the enhanced efficiency of virtualized data centre environments despite encountering challenges related to Make Span.

[76] addressed problems related to underutilization and overutilization in cloud data centers by introducing an autonomous resource allocation model. This model aimed to diminish request waiting times and optimize Virtual Machine (VM) allocation based on workload.

Several studies emphasized the importance of effective task scheduling and workload contribution to energy savings. [77] introduced the Load Balancing and Task Completion Cost Genetic Algorithm (LCGA) for task scheduling, successfully achieving both load balancing and minimization of completion costs simultaneously. Similarly, [78] introduced energy-saving resource allocation algorithms to contribute to workload and reduce energy consumption in cloud data centres [69].

4. Quantum Computing in Coud Environment

[79] as well as [80] both focus on assessing the performance of different cloud quantum computing platforms, albeit with different methodologies. Algorithm development for quantum computing is a prominent area of research. [81] proposes a quantum k-means algorithm, study aim to address specific challenges in quantum computing, highlighting the importance of algorithmic advancements. Architectural frameworks and resource management are key considerations. [82] presents an architectural framework for integrating quantum computing into existing enterprise architectures, emphasizing the importance

of efficient resource utilization. [80] analyses resource consumption and management trends in quantum cloud systems, highlighting the need for optimized resource allocation. Lastly, cryptographic techniques play a crucial role in ensuring the security and privacy of quantum data. [83] explores cryptographic verification for quantum cloud computing, while [84] proposes a quantum homomorphic encryption scheme. Both studies contribute to enhancing security measures in quantum cloud environments. Overall, these similarities underscore the multifaceted nature of research in cloud quantum computing, encompassing performance evaluation, algorithm development, architectural integration, resource management, and security considerations.

5. Challenges and Future Directions:

Table- 4: Challenges in the field of Cloud Computing with their probable solutions. [85], [86]

Challenges	Description	Solution
Privacy & Data Security	Notable concerns arise regarding the security, accountability, and privacy of data within Cloud environments. These concerns stem from factors such as limited visibility, challenges with identity access management, potential data misuse, and misconfigurations within the Cloud.	Employ measures such as setting up network hardware, applying the latest software updates, utilizing firewalls and antivirus software, and enhancing bandwidth to optimize the availability and security of Cloud data.
Multi-Cloud Environments	The management of multi-cloud environments poses various challenges, including configuration errors, inadequate security patching, concerns regarding data governance, and granularity issues. Moreover, tracking security requirements and enforcing data management policies across diverse cloud platforms can be particularly daunting.	Utilize multi-cloud data management solutions and employ tools like Terraform to maintain control over complex multi-cloud architectures, thereby addressing the complexities associated with managing multiple cloud environments effectively.
Performance Challenges	Cloud computing performance is contingent upon the reliability of service providers, with potential implications for business operations in the event of vendor downtime.	Mitigate performance concerns by enrolling with Cloud Service Providers offering real-time Software as a Service (SaaS) monitoring policies, and consider Cloud Solution Architect Certification training to ensure optimal performance even during challenging situations.
Interoperability & Flexibility	Challenges arise with interoperability when transitioning applications between different Cloud ecosystems, involving tasks such as rebuilding application stacks, handling data encryption during migration, setting up networks, and managing apps and services in the target cloud ecosystem.	Establish standards for Cloud interoperability and portability before project initiation, and implement multi-layer authentication and authorization tools for verifying accounts across public, private, and hybrid cloud ecosystems.
High Dependence on Network	Insufficient internet bandwidth during large data transfers can render data vulnerable to sudden outages.	Address network dependencies by investing in higher bandwidth and focusing on improving operational efficiency to ensure seamless data transfer and accessibility.
Lack of Knowledge and Expertise	The shortage of qualified Cloud talent, especially in DevOps and automation, poses challenges in finding and hiring professionals with the necessary skills and knowledge.	Bridge the skills gap by retraining existing IT staff and investing in Cloud training programs to enhance their expertise and capabilities in managing cloud infrastructure effectively.
Reliability and Availability	Concerns regarding the high unavailability of Cloud services and a lack of reliability may necessitate additional computing resources.	Improve reliability and availability by implementing NIST Framework standards in Cloud environments, thus ensuring consistent service delivery and minimizing disruptions in business operations.
Password Security	Critical issues with password management, including	Enhance password security by deploying a

	the use of the same passwords across multiple Cloud accounts.	robust password management solution and implementing Multifactor Authentication (MFA) alongside a password manager to strengthen account security and mitigate the risk of unauthorized access.
Cost Management	Challenges persist in managing costs effectively despite the pay-as-you-go model, with hidden costs often arising from underutilized resources.	Manage costs efficiently through regular system audits and the implementation of resource utilization monitoring tools to optimize budgets and ensure optimal resource allocation across cloud infrastructure.
Lack of Expertise	The scarcity of professionals with the requisite skills and knowledge for Cloud computing contributes to a gap in supply and demand within the industry.	Address the lack of expertise by retraining existing IT staff and investing in Cloud training programs to cultivate a skilled workforce capable of effectively managing and optimizing cloud infrastructure.
Control or Governance	Governance issues may arise, leading to the utilization of tools that do not align with the organization's vision, and challenges may arise in gaining total control of compliance, risk management, and data quality checks during Cloud migration.	Ensure effective governance by adopting traditional IT processes to accommodate Cloud migrations and implementing measures to align tools and practices with organizational goals and compliance requirements, thus facilitating seamless transition and adherence to regulatory standards.
Compliance	Challenges arise from Cloud Service Providers lacking up-to-date data compliance policies, along with compliance issues concerning state laws and regulations during data transfers to the Cloud.	Expect improvements in compliance by anticipating advancements in compliance standards such as the General Data Protection Regulation (GDPR) Act for Cloud Service Providers, thereby ensuring data protection and regulatory compliance throughout the data lifecycle within the Cloud environment.
Multiple Cloud Management	Managing multiple cloud environments poses challenges, particularly with the adoption of hybrid cloud strategies, leading to increased complexity due to technological differences and cloud computing challenges.	Implement effective data management and privacy policies to streamline the management of multi-cloud environments, thus enhancing operational efficiency and ensuring seamless integration and collaboration across diverse cloud platforms and services.
Migration	Challenges in migrating data to the Cloud may result in increased downtimes, security issues, and problems with data formatting and conversions.	Facilitate smooth data migration by employing in-house professionals with expertise in Cloud data migration and increasing investments in analyzing cloud computing issues and solutions before adopting new platforms and services offered by Cloud Service Providers.
Hybrid-Cloud Complexity	Mixed computing, storage, and services in hybrid cloud environments may lead to complexity in managing private cloud services, public Clouds, and on-premises infrastructures across various platforms.	Address hybrid-cloud complexity by utilizing centralized Cloud management solutions, increasing automation, and implementing robust security measures to streamline operations and mitigate complexities associated with managing diverse cloud environments.

Approaching the years 2025 to 2030, the future trajectory of cloud computing promises notable advancements. Several predictions outline the evolving landscape:

5.1. **Hybrid and Multi-Cloud Adoption:** Organizations are anticipated to progressively incorporate hybrid and multi-cloud strategies, strategically utilizing multiple cloud providers to optimize features and services tailored to their specific needs

[87]. According to empirical survey findings from a cloud-based security firm, Trend Micro, it has been observed that "public cloud services may not fully align with the IT and business requisites of certain business organizations." Conversely, the perceived "safer option," namely the private cloud, necessitates substantial investments in infrastructure and operational development, accompanied by the acquisition of new skill sets by the IT staff. While strategies exist to address each of these concerns independently, the overarching trend is expected to steer towards the adoption of hybrid environments, encompassing a blend of these cloud configurations and various non-cloud environments [88].

5.2. **Rise of Edge Computing:** Limitations inherent in the current cloud computing model are primarily associated with the substantial volume and rapid accumulation of data from Internet of Things (IoT) devices, latency issues stemming from the considerable distance between edge IoT devices and centralized data centres, and concerns related to the monopolistic tendencies in contrast to fostering open competition within the IoT landscape. Addressing these challenges can be achieved through the implementation of open-edge cloud infrastructures. Firstly, these infrastructures facilitate the provision of local computing, storage, and networking resources to augment the often resource-constrained IoT devices. The overwhelming data generated by edge devices can be efficiently stored and pre-processed locally, mitigating the need for transmitting large volumes of raw data back to central data centres and consequently reducing networking loads. Secondly, by allowing IoT devices to offload their tasks to edge servers when their computational capacities are exceeded, the latency, attributable to the proximity of edge cloud infrastructure to the devices, can be effectively managed. This represents a notable improvement compared to the conventional cloud computing model. Thirdly, the adoption of an open-edge cloud innovation platform has the potential to dismantle monopolies, fostering a more equitable and competitive environment. This inclusive platform accommodates fair competition among various stakeholders, whether they are major corporations or smaller entities such as inventors, vendors, or Application Service Providers (ASPs). Particularly, smaller stakeholders, often closer to end-users, are recognized as dynamic and innovative contributors to the internet community. Establishing such an open environment is conducive to nurturing future innovations in the field of edge computing [87], [89], [90], [91], [92].
[93] discusses the integration of edge computing with cloud computing, emphasizing its role in reducing data transmission costs and enhancing overall system performance by processing data at the network's edge. They emphasize the benefits of pre-processing data at the edge, including shortened response times and reduced vulnerabilities.

Similarly, [94] delves into the significance of edge computing for IoT applications, highlighting its ability to alleviate resource congestion and reduce latency by relocating data computation and storage closer to end users. They conduct a survey to categorize edge computing architectures and analyze their performance across various metrics, including network latency, bandwidth, energy consumption, and security.

[95] discusses the role of edge computing in enhancing agility, real-time processing, and autonomy in intelligent manufacturing within the Industrial IoT framework. They propose an edge computing architecture tailored for IoT-based manufacturing, examining its impact on various aspects such as edge equipment, network communication, and cooperative mechanisms with cloud computing. The study offers practical insights through a case study on active maintenance implementation, serving as a technical reference for deploying edge computing in smart factories. Similarly, [96] address the scalability issues associated with centralized cloud infrastructures for IoT data analysis. They propose distributing IoT analytics between core cloud and network edge to alleviate congestion and improve resource utilization. The paper introduces an IoT-aware multilayer transport software-defined networking and edge/cloud orchestration architecture, validating a dynamic IoT traffic control mechanism that deploys processing to the edge based on network resource state. This approach efficiently integrates packet and optical transport networks to enable the dynamic distribution of IoT analytics and optimize network resources.

[97] emphasize the potential of edge computing to reduce latencies and network traffic by moving computation closer to data sources. They propose a combined edge and cloud computing approach for IoT data analytics, leveraging edge nodes for data preprocessing and feature learning to minimize data transfer. Similarly, [98] discusses the impact of edge computing on IoT, focusing on its ability to extend cloud computing capabilities to the network edge. They categorize existing literature to establish a taxonomy of edge computing, highlighting its supportive features and indispensable scenarios in IoT applications.

[99] introduces the concept of Cloud of Things (CoTs), which integrates IoT with cloud computing to manage the increasing volume of data generated by IoT devices. They discuss the architecture, working principles, and issues involved in CoTs, emphasizing its importance in creating valuable services through the amalgamation of IoT and cloud computing.

[100] propose a flexible IoT edge computing architecture based on multi-agent systems to balance global optimization by the cloud and local optimization by edge nodes. They demonstrate the effectiveness of their proposal through an energy management system application, highlighting the dynamic optimization of cloud and edge server roles.

[101] addresses the challenges and opportunities in integrating IoT with cloud computing. They discuss the exponential growth of IoT data and the constraints of IIoT devices, emphasizing the importance of outsourced data storage and cloud-compatible computing techniques to facilitate the transition of IoT applications to the cloud. Overall, these studies underscore the significance of edge computing in enhancing data processing efficiency, reducing network congestion, and enabling innovative IoT applications through the integration of edge and cloud computing paradigms.

5.3. **AI and Machine Learning Integration:** Cloud service providers are positioned to significantly augment their investments in artificial intelligence (AI) and machine learning (ML). This strategic emphasis is geared towards enabling advanced functionalities, specifically in the realms of automatic scaling and self-healing systems within cloud infrastructures. The recent surge in data generation, coupled with substantial advancements in computing power, particularly in Graphics Processing Units (GPUs), has propelled AI into the spotlight. Notably, algorithms and models for machine learning and deep learning have garnered considerable attention among both researchers and practitioners in the field of Cloud computing. The symbiotic relationship between Cloud computing and machine/deep learning is evident. On one hand, the Cloud stands to benefit from the integration of machine/deep learning, enhancing resource management optimization. Conversely, the Cloud serves as an indispensable platform for hosting machine/deep learning services, capitalizing on its pay-as-you-go model and seamless accessibility to computing resources. Many machine learning and deep learning algorithms necessitate extensive computing power and access to external data sources, factors that can be more cost-effective and streamlined through Cloud deployment compared to on-premise infrastructure. The current landscape emphasizes the significance of executing technologies for training intricate machine/deep learning models in parallel at a scalable level. This trend has led numerous companies to offer AI-related services in the Cloud, exemplified by platforms such as IBM Watson, Microsoft Azure Machine Learning, AWS Deep Learning AMIs, Google Cloud Machine Learning Engine, among others. The integration of AI services within the Cloud framework underscores the growing synergy between advanced computational capabilities and scalable, accessible resources in the pursuit of innovation [87], [102], [103]. According to different studies, diverse applications of artificial intelligence (AI) and machine learning (ML) across several domains, including cloud computing, Internet of Things (IoT), sports, security, and healthcare. [12] delves into the applications of AI and ML in cloud computing and IoT, offering a comprehensive review of the challenges encountered and technological advancements achieved in these domains.[104] underscores the transformative potential of AI, ML, and cloud computing in sports, emphasizing their role in optimizing performance, enhancing fan experiences, and unlocking new capabilities in athlete management and game strategy. [105] examines the use of ML algorithms to address security challenges in cloud computing, presenting various techniques and their efficacy in mitigating security threats, thereby contributing to enhanced data protection and privacy. [106] explores the integration of AI and deep learning techniques in cloud computing to improve operational efficiency, focusing on resource management, scalability, and dependability issues, with a view to optimizing cloud services and infrastructure. [107] discuss the integration challenges of AI in cloud computing, IoT, and software-defined networking, highlighting both the opportunities and complexities involved in combining these technologies to harness their full potential.
Lastly, [108] elaborate on the practical implementation of AI-based deep learning and cloud computing in the diagnosis and treatment of rheumatoid arthritis (RA), showcasing the transformative impact of AI on healthcare by enabling more accurate diagnoses, personalized treatment plans, and improved patient outcomes.

5.4. **Enhanced Security Focus:** As the upward trajectory of cloud utilization continues, a heightened emphasis on security is anticipated. Projections indicate substantial investments in cutting-edge security technologies, concomitant with the implementation of rigorous data access controls. This strategic approach positions security as a paramount concern within the field of cloud computing [103], [109], [110].

5.5. **Ongoing Price Competitions:** The intensification of competition among cloud providers is foreseen to fuel persistent price wars. This competitive environment is expected to result in continual reductions in service costs, thereby benefiting consumers [87].

5.6. **Increased Regulation:** The pervasive ubiquity of cloud services is anticipated to prompt heightened regulatory measures, particularly concerning data privacy and security. This regulatory landscape aims to safeguard user rights and ensure provider accountability in the evolving cloud computing paradigm [87].

6. Conclusion:

The of cloud computing has undergone significant transformations, evolving from its humble origins to become an indispensable cornerstone of modern IT infrastructure. Virtualization and containerization have revolutionized the way computing resources are managed and deployed, offering unparalleled scalability and efficiency benefits. In the time frame of 2025 to 2030, several trends and challenges emerge on the horizon. The adoption of hybrid and multi-cloud strategies is poised to accelerate, enabling organizations to optimize features and services tailored to their specific needs while mitigating risks associated with vendor lock-in. The rise of edge computing promises to address latency issues and foster a more equitable and competitive IoT landscape, while AI and machine learning integration within cloud frameworks are set to unlock new realms of innovation and optimization. Along with advancements, there will are and will be many challenges to address like, enhanced security measures are imperative to safeguard sensitive data and ensure user privacy in the face of evolving cyber threats. Ongoing price competitions among cloud providers may lead to continual reductions in service costs, benefiting consumers but potentially impacting providers' profitability. Increased regulation is also anticipated to shape the future of cloud computing, with a focus on data privacy and security to uphold user rights and ensure provider accountability. After analysing the present state of cloud computing, it can be assured that cloud computing will continue to play a pivotal role in driving digital innovation and empowering organizations to thrive in an increasingly interconnected world. By embracing emerging technologies, addressing security concerns, and adapting to evolving regulatory frameworks, businesses can leverage the power of the cloud to unlock new opportunities and stay ahead in an ever-changing marketplace.

References:

[1] M. Vuyyuru, P. Annapurna, K. G. Babu, and A. S. K. Ratnam, "An overview of cloud computing technology," *International Journal of Soft Computing and Engineering*, vol. 2, no. 3, pp. 244–247, 2012.

[2] L. Qian, Z. Luo, Y. Du, and L. Guo, "Cloud computing: An overview," in *Cloud Computing: First International Conference, CloudCom 2009, Beijing, China, December 1-4, 2009. Proceedings 1*, Springer, 2009, pp. 626–631.

[3] J. Hong, T. Dreibholz, J. A. Schenkel, and J. A. Hu, "An overview of multi-cloud computing," in *Web, Artificial Intelligence and Network Applications: Proceedings of the Workshops of the 33rd International Conference on Advanced Information Networking and Applications (WAINA-2019) 33*, Springer, 2019, pp. 1055–1068.

[4] Y. Coady, O. Hohlfeld, J. Kempf, R. McGeer, and S. Schmid, "Distributed cloud computing: Applications, status quo, and challenges," *ACM SIGCOMM Computer Communication Review*, vol. 45, no. 2, pp. 38–43, 2015.

[5] S. Goyal, "Public vs private vs hybrid vs community-cloud computing: a critical review," *International Journal of Computer Network and Information Security*, vol. 6, no. 3, pp. 20–29, 2014.

[6] L. Qian, Z. Luo, Y. Du, and L. Guo, "Cloud computing: An overview," in *Cloud Computing: First International Conference, CloudCom 2009, Beijing, China, December 1-4, 2009. Proceedings 1*, Springer, 2009, pp. 626–631.

[7] Andriy Varusha, "8 biggest cloud computing trends of 2024," https://www.n-ix.com/cloud-computing-trends/#:~:text=7%20min%20read-,8%20biggest%20cloud%20computing%20trends%20of%202024,%241T%20globally%20in%202024.

[8] Keith D. Foote, "Cloud Computing Trends in 2024," https://www.dataversity.net/cloud-computing-trends-in-2024/.

[9] Matthew David, "21 Cloud Computing Trends That Will Dominate in 2024!," https://www.simplilearn.com/trends-in-cloud-computing-article.

[10] M. Oltrogge *et al.*, "The rise of the citizen developer: Assessing the security impact of online app generators," in *2018 IEEE Symposium on Security and Privacy (SP)*, IEEE, 2018, pp. 634–647.

[11] S. Mishra and A. K. Tyagi, "The role of machine learning techniques in internet of things-based cloud applications," *Artificial intelligence-based internet of things systems*, pp. 105–135, 2022.

[12] M. Rath, J. Satpathy, and G. S. Oreku, "Artificial intelligence and machine learning applications in cloud computing and Internet of Things," in *Artificial intelligence to solve pervasive internet of things issues*, Elsevier, 2021, pp. 103–123.

[13] H. C. Lim, S. Babu, J. S. Chase, and S. S. Parekh, "Automated control in cloud computing: challenges and opportunities," in *Proceedings of the 1st workshop on Automated control for datacenters and clouds*, 2009, pp. 13–18.

[14] O. Givehchi, H. Trsek, and J. Jasperneite, "Cloud computing for industrial automation systems—A comprehensive overview," in *2013 IEEE 18th Conference on Emerging Technologies & Factory Automation (ETFA)*, IEEE, 2013, pp. 1–4.

[15] B. Gupta, P. Mittal, and T. Mufti, "A review on amazon web service (aws), microsoft azure & google cloud platform (gcp) services," in *Proceedings of the 2nd International Conference on ICT for Digital, Smart, and Sustainable Development, ICIDSSD 2020, 27-28 February 2020, Jamia Hamdard, New Delhi, India*, 2021.

[16] J. Shah and D. Dubaria, "Building modern clouds: using docker, kubernetes & Google cloud platform," in *2019 IEEE 9th Annual Computing and Communication Workshop and Conference (CCWC)*, IEEE, 2019, pp. 184–189.

[17] S. N. Shirazi, A. Gouglidis, A. Farshad, and D. Hutchison, "The extended cloud: Review and analysis of mobile edge computing and fog from a security and resilience perspective," *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 11, pp. 2586–2595, 2017.

[18] J. Hong, T. Dreibholz, J. A. Schenkel, and J. A. Hu, "An overview of multi-cloud computing," in *Web, Artificial Intelligence and Network Applications: Proceedings of the Workshops of the 33rd International Conference on Advanced Information Networking and Applications (WAINA-2019) 33*, Springer, 2019, pp. 1055–1068.

[19] R. S. S. Dittakavi, "Evaluating the Efficiency and Limitations of Configuration Strategies in Hybrid Cloud Environments," *International Journal of Intelligent Automation and Computing*, vol. 5, no. 2, pp. 29–45, 2022.

[20] S. R. Gundu, C. A. Panem, and A. Thimmapuram, "Hybrid IT and multi cloud an emerging trend and improved performance in cloud computing," *SN Comput Sci*, vol. 1, no. 5, p. 256, 2020.

[21] E. N. Alkhanak, S. P. Lee, R. Rezaei, and R. M. Parizi, "Cost optimization approaches for scientific workflow scheduling in cloud and grid computing: A review, classifications, and open issues," *Journal of Systems and Software*, vol. 113, pp. 1–26, 2016.

[22] P. Osypanka and P. Nawrocki, "Resource usage cost optimization in cloud computing using machine learning," *IEEE Transactions on Cloud Computing*, vol. 10, no. 3, pp. 2079–2089, 2020.

[23] Y. Mao, C. You, J. Zhang, K. Huang, and K. B. Letaief, "A survey on mobile edge computing: The communication perspective," *IEEE communications surveys & tutorials*, vol. 19, no. 4, pp. 2322–2358, 2017.

[24] E. N. Alkhanak, S. P. Lee, R. Rezaei, and R. M. Parizi, "Cost optimization approaches for scientific workflow scheduling in cloud and grid computing: A review, classifications, and open issues," *Journal of Systems and Software*, vol. 113, pp. 1–26, 2016.

[25] A. Z. Abualkishik, A. A. Alwan, and Y. Gulzar, "Disaster recovery in cloud computing systems: An overview," *International Journal of Advanced Computer Science and Applications*, vol. 11, no. 9, 2020.

[26] K. Sharma and K. R. Singh, "Online data back-up and disaster recovery techniques in cloud computing: A review," *International Journal of Engineering and Innovative Technology (IJEIT)*, vol. 2, no. 5, pp. 249–254, 2012.

[27] H.-J. Hong, F.-C. Tao-Ya, C.-H. Hsu, K.-T. Chen, and C.-Y. Huang, "GPU consolidation for cloud games: Are we there yet?," in *2014 13th Annual Workshop on Network and Systems Support for Games*, IEEE, 2014, pp. 1–6.

[28] W. Cai *et al.*, "A survey on cloud gaming: Future of computer games," *IEEE Access*, vol. 4, pp. 7605–7620, 2016.

[29] A. Wibowo and T. N. B. Duong, "CloudNPlay: Resource optimization for a cloud-native gaming system," in *2021 IEEE 30th International Conference on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE)*, IEEE, 2021, pp. 33–38.

[30] Z. Li, L. Guo, J. Cheng, Q. Chen, B. He, and M. Guo, "The serverless computing survey: A technical primer for design architecture," *ACM Computing Surveys (CSUR)*, vol. 54, no. 10s, pp. 1–34, 2022.

[31] Y. Li, Y. Lin, Y. Wang, K. Ye, and C. Xu, "Serverless computing: state-of-the-art, challenges and opportunities," *IEEE Trans Serv Comput*, vol. 16, no. 2, pp. 1522–1539, 2022.

[32] G. McGrath and P. R. Brenner, "Serverless computing: Design, implementation, and performance," in *2017 IEEE 37th International Conference on Distributed Computing Systems Workshops (ICDCSW)*, IEEE, 2017, pp. 405–410.

[33] H. B. Hassan, S. A. Barakat, and Q. I. Sarhan, "Survey on serverless computing," *Journal of Cloud Computing*, vol. 10, pp. 1–29, 2021.

[34] K. Gai, J. Guo, L. Zhu, and S. Yu, "Blockchain meets cloud computing: A survey," *IEEE Communications Surveys & Tutorials*, vol. 22, no. 3, pp. 2009–2030, 2020.

[35] C. V. N. U. B. Murthy, M. L. Shri, S. Kadry, and S. Lim, "Blockchain based cloud computing: Architecture and research challenges," *IEEE access*, vol. 8, pp. 205190–205205, 2020.

[36] A. Gupta, S. T. Siddiqui, S. Alam, and M. Shuaib, "Cloud computing security using blockchain," *Journal of Emerging Technologies and Innovative Research (JETIR)*, vol. 6, no. 6, pp. 791–794, 2019.

[37] C. Stergiou, K. E. Psannis, B.-G. Kim, and B. Gupta, "Secure integration of IoT and cloud computing," *Future Generation Computer Systems*, vol. 78, pp. 964–975, 2018.

[38] A. Bhawiyuga, D. P. Kartikasari, K. Amron, O. B. Pratama, and M. W. Habibi, "Architectural design of IoT-cloud computing integration platform," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 17, no. 3, pp. 1399–1408, 2019.

[39] T. D. Cordeiro *et al.*, "Open source cloud computing platforms," in *2010 Ninth International Conference on Grid and Cloud Computing*, IEEE, 2010, pp. 366–371.

[40] P. T. Endo, G. E. Gonçalves, J. Kelner, and D. Sadok, "A survey on open-source cloud computing solutions," in *Brazilian symposium on computer networks and distributed systems*, Citeseer, 2010, pp. 3–16.

[41] C. Y. Hyun, "Design and implementation of a low-code/no-code system," *International journal of advanced smart convergence*, vol. 8, no. 4, pp. 188–193, 2019.

[42] M. A. M. Popescu, P. C. Simion, I. C. Costea-Marcu, and D. Dumitriu, "ANALYSIS OF LOW-CODE DEVELOPMENT PLATFORMS," in *International Conference on Management and Industrial Engineering*, Niculescu Publishing House, 2021, pp. 256–263.

[43] F. Khorram, J.-M. Mottu, and G. Sunyé, "Challenges & opportunities in low-code testing," in *Proceedings of the 23rd ACM/IEEE International Conference on Model Driven Engineering Languages and Systems: Companion Proceedings*, 2020, pp. 1–10.

[44] Z. Yan, "The impacts of low/no-code development on digital transformation and software development," *arXiv preprint arXiv:2112.14073*, 2021.

[45] N. Kratzke and P.-C. Quint, "Understanding cloud-native applications after 10 years of cloud computing-a systematic mapping study," *Journal of Systems and Software*, vol. 126, pp. 1–16, 2017.

[46] D. Gannon, R. Barga, and N. Sundaresan, "Cloud-native applications," *IEEE Cloud Computing*, vol. 4, no. 5, pp. 16–21, 2017.

[47] G. Toffetti, S. Brunner, M. Blöchlinger, J. Spillner, and T. M. Bohnert, "Self-managing cloud-native applications: Design, implementation, and experience," *Future Generation Computer Systems*, vol. 72, pp. 165–179, 2017.

[48] D. S. Linthicum, "Cloud-native applications and cloud migration: The good, the bad, and the points between," *IEEE Cloud Computing*, vol. 4, no. 5, pp. 12–14, 2017.

[49] S. Rangaraju, S. Ness, and R. Dharmalingam, "Incorporating AI-Driven Strategies in DevSecOps for Robust Cloud Security," *Int J Innov Sci Res Technol*, vol. 8, no. 23592365, pp. 10–5281, 2023.

[50] M. Bafana and A. Abdulaziz, "DevSecOps in AWS: Embedding Security into the Heart of DevOps Practices," *Asian American Research Letters Journal*, vol. 1, no. 1, 2024.

[51] N. G. Camacho, "Unlocking the Potential of AI/ML in DevSecOps: Effective Strategies and Optimal Practices," *Journal of Artificial Intelligence General science (JAIGS) ISSN: 3006-4023*, vol. 2, no. 1, pp. 79–89, 2024.

[52] W. Li, Y. Lemieux, J. Gao, Z. Zhao, and Y. Han, "Service mesh: Challenges, state of the art, and future research opportunities," in *2019 IEEE International Conference on Service-Oriented System Engineering (SOSE)*, IEEE, 2019, pp. 122–1225.

[53] X. I. E. Xiaojing and S. S. Govardhan, "A service mesh-based load balancing and task scheduling system for deep learning applications," in *2020 20th IEEE/ACM International Symposium on Cluster, Cloud and Internet Computing (CCGRID)*, IEEE, 2020, pp. 843–849.

[54] R. R. Harmon and N. Auseklis, “Sustainable IT services: Assessing the impact of green computing practices,” in *PICMET’09-2009 Portland International Conference on Management of Engineering & Technology*, IEEE, 2009, pp. 1707–1717.

[55] J. Park, K. Han, and B. Lee, “Green cloud? An empirical analysis of cloud computing and energy efficiency,” *Manage Sci*, vol. 69, no. 3, pp. 1639–1664, 2023.

[56] P. Sasikala, “Energy efficiency in cloud computing: way towards green computing,” *International Journal of Cloud Computing*, vol. 2, no. 4, pp. 305–324, 2013.

[57] Y. Xing and Y. Zhan, “Virtualization and cloud computing,” in *Future Wireless Networks and Information Systems: Volume 1*, Springer, 2012, pp. 305–312.

[58] A. Bhardwaj and C. R. Krishna, “Virtualization in cloud computing: Moving from hypervisor to containerization—a survey,” *Arab J Sci Eng*, vol. 46, no. 9, pp. 8585–8601, 2021.

[59] L. Malhotra, D. Agarwal, and A. Jaiswal, “Virtualization in cloud computing,” *J. Inform. Tech. Softw. Eng*, vol. 4, no. 2, pp. 1–3, 2014.

[60] V. K. Sharma, A. Singh, K. R. Jaya, A. K. Bairwa, and D. K. Srivastava, “Introduction to virtualization in cloud computing,” in *Machine Learning and Optimization Models for Optimization in Cloud*, Chapman and Hall/CRC, 2022, pp. 1–14.

[61] Y. Chen *et al.*, “High-performance and Scalable Software-based NVMe Virtualization Mechanism with I/O Queues Passthrough,” *arXiv preprint arXiv:2304.05148*, 2023.

[62] G. Goel, P. Tanwar, V. Bansal, and S. Sharma, “The challenges and issues with virtualization in cloud computing,” in *2021 5th International Conference on Trends in Electronics and Informatics (ICOEI)*, IEEE, 2021, pp. 1334–1338.

[63] H. Aqasizade, E. Ataie, and M. Bastam, “Experimental Assessment of Containers Running on Top of Virtual Machines,” *arXiv preprint arXiv:2401.07539*, 2024.

[64] S. B. Verma, B. Pandey, and B. K. Gupta, “Containerization and its architectures: a study,” *ADCAIJ: Advances in Distributed Computing and Artificial Intelligence Journal*, vol. 11, no. 4, pp. 395–409, 2022.

[65] N. Zhou, H. Zhou, and D. Hoppe, “Containerization for high performance computing systems: Survey and prospects,” *IEEE Transactions on Software Engineering*, vol. 49, no. 4, pp. 2722–2740, 2022.

[66] Ltd. Huawei Technologies Co., “Cloud Computing Development Trends,” in *Cloud Computing Technology*, Springer, 2022, pp. 343–374.

[67] Y. Zhou, B. Subramaniam, K. Keahey, and J. Lange, “Comparison of virtualization and containerization techniques for high performance computing,” in *Proceedings of the 2015 ACM/IEEE conference on Supercomputing*, 2015.

[68] T. Deepika and A. N. Rao, “Active resource provision in cloud computing through virtualization,” in *2014 IEEE International Conference on Computational Intelligence and Computing Research*, IEEE, 2014, pp. 1–4.

[69] H. Shukur, S. Zeebaree, R. Zebari, D. Zeebaree, O. Ahmed, and A. Salih, “Cloud computing virtualization of resources allocation for distributed systems,” *Journal of Applied Science and Technology Trends*, vol. 1, no. 2, pp. 98–105, 2020.

[70] M. J. Usman, A. Samad, H. Chizari, and A. Aliyu, “Energy-Efficient virtual machine allocation technique using interior search algorithm for cloud datacenter,” in *2017 6th ICT international student project conference (ICT-ISPC)*, IEEE, 2017, pp. 1–4.

[71] C.-F. Wang, W.-Y. Hung, and C.-S. Yang, “A prediction based energy conserving resources allocation scheme for cloud computing,” in *2014 IEEE International Conference on Granular Computing (GrC)*, IEEE, 2014, pp. 320–324.

[72] S. B. Akintoye and A. Bagula, “Optimization of virtual resources allocation in cloud computing environment,” in *2017 IEEE AFRICON*, IEEE, 2017, pp. 873–880.

[73] P. Pradhan, P. K. Behera, and B. N. B. Ray, "Modified round robin algorithm for resource allocation in cloud computing," *Procedia Comput Sci*, vol. 85, pp. 878–890, 2016.

[74] M. Padmavathi and S. M. Basha, "Dynamic and elasticity ACO load balancing algorithm for cloud computing," in *2017 International conference on intelligent computing and control systems (ICICCS)*, IEEE, 2017, pp. 77–81.

[75] S. Atiewi, A. Abuhussein, and M. A. Saleh, "Impact of virtualization on cloud computing energy consumption: Empirical study," in *Proceedings of the 2nd International Symposium on Computer Science and Intelligent Control*, 2018, pp. 1–7.

[76] T. Bhardwaj, H. Upadhyay, and S. C. Sharma, "Autonomic resource allocation mechanism for service-based cloud applications," in *2019 international conference on computing, communication, and intelligent systems (ICCCIS)*, IEEE, 2019, pp. 183–187.

[77] S. Yin, P. Ke, and L. Tao, "An improved genetic algorithm for task scheduling in cloud computing," in *2018 13th IEEE Conference on Industrial Electronics and Applications (ICIEA)*, IEEE, 2018, pp. 526–530.

[78] M. M. Than and T. Thein, "Energy-saving resource allocation in cloud data centers," in *2020 IEEE Conference on Computer Applications (ICCA)*, IEEE, 2020, pp. 1–6.

[79] H. Soeparno and A. S. Perbangsa, "Cloud quantum computing concept and development: A systematic literature review," *Procedia Comput Sci*, vol. 179, pp. 944–954, 2021.

[80] G. S. Ravi, K. N. Smith, P. Gokhale, and F. T. Chong, "Quantum computing in the cloud: Analyzing job and machine characteristics," in *2021 IEEE International Symposium on Workload Characterization (IISWC)*, IEEE, 2021, pp. 39–50.

[81] C. Gong, Z. Dong, A. Gani, and H. Qi, "Quantum k-means algorithm based on trusted server in quantum cloud computing," *Quantum Inf Process*, vol. 20, pp. 1–22, 2021.

[82] M. Grossi *et al.*, "A serverless cloud integration for quantum computing," *arXiv preprint arXiv:2107.02007*, 2021.

[83] X. Chen *et al.*, "Experimental cryptographic verification for near-term quantum cloud computing," *Sci Bull (Beijing)*, vol. 66, no. 1, pp. 23–28, 2021.

[84] C. Gong *et al.*, "Grover algorithm-based quantum homomorphic encryption ciphertext retrieval scheme in quantum cloud computing," *Quantum Inf Process*, vol. 19, pp. 1–17, 2020.

[85] Kingson Jebaraj, "Top 15 Cloud Computing Challenges [with Solution]," https://www.knowledgehut.com/blog/cloud-computing/cloud-computing-challenges.

[86] Ayush Saxena, "Navigating the Challenges of Cloud Computing," https://sprinto.com/blog/challenges-in-cloud-computing/.

[87] MAPL World, "The Future of Cloud Computing 2025-2030," https://www.linkedin.com/pulse/future-cloud-computing-2025-2030-maplworld.

[88] S. U. Khan, H. U. Khan, N. Ullah, and R. A. Khan, "Challenges and their practices in adoption of hybrid cloud computing: An analytical hierarchy approach," *Security and Communication Networks*, vol. 2021, pp. 1–20, 2021.

[89] M. Nikravan and M. H. Kashani, "A review on trust management in fog/edge computing: Techniques, trends, and challenges," *Journal of Network and Computer Applications*, vol. 204, p. 103402, 2022.

[90] J. Moura and D. Hutchison, "Game theory for multi-access edge computing: Survey, use cases, and future trends," *IEEE Communications Surveys & Tutorials*, vol. 21, no. 1, pp. 260–288, 2018.

[91] J. Pan and J. McElhannon, "Future edge cloud and edge computing for internet of things applications," *IEEE Internet Things J*, vol. 5, no. 1, pp. 439–449, 2017.

[92] G. Carvalho, B. Cabral, V. Pereira, and J. Bernardino, "Edge computing: current trends, research challenges and future directions," *Computing*, vol. 103, no. 5, pp. 993–1023, 2021.

[93] S. Mittal, N. Negi, and R. Chauhan, "Integration of edge computing with cloud computing," in *2017 International Conference on Emerging Trends in Computing and Communication Technologies (ICETCCT)*, IEEE, 2017, pp. 1–6.

[94] W. Yu *et al.*, "A survey on the edge computing for the Internet of Things," *IEEE access*, vol. 6, pp. 6900–6919, 2017.

[95] B. Chen, J. Wan, A. Celesti, D. Li, H. Abbas, and Q. Zhang, "Edge computing in IoT-based manufacturing," *IEEE Communications Magazine*, vol. 56, no. 9, pp. 103–109, 2018.

[96] R. Muñoz *et al.*, "Integration of IoT, transport SDN, and edge/cloud computing for dynamic distribution of IoT analytics and efficient use of network resources," *Journal of Lightwave Technology*, vol. 36, no. 7, pp. 1420–1428, 2018.

[97] A. M. Ghosh and K. Grolinger, "Edge-cloud computing for Internet of Things data analytics: Embedding intelligence in the edge with deep learning," *IEEE Trans Industr Inform*, vol. 17, no. 3, pp. 2191–2200, 2020.

[98] N. Hassan, S. Gillani, E. Ahmed, I. Yaqoob, and M. Imran, "The role of edge computing in internet of things," *IEEE communications magazine*, vol. 56, no. 11, pp. 110–115, 2018.

[99] M. Aazam, E.-N. Huh, M. St-Hilaire, C.-H. Lung, and I. Lambadaris, "Cloud of things: integration of IoT with cloud computing," *Robots and sensor clouds*, pp. 77–94, 2016.

[100] T. Ogino, S. Kitagami, T. Suganuma, and N. Shiratori, "A multi-agent based flexible IoT edge computing architecture harmonizing its control with cloud computing," *International Journal of Networking and Computing*, vol. 8, no. 2, pp. 218–239, 2018.

[101] M. M. Sadeeq, N. M. Abdulkareem, S. R. M. Zeebaree, D. M. Ahmed, A. S. Sami, and R. R. Zebari, "IoT and Cloud computing issues, challenges and opportunities: A review," *Qubahan Academic Journal*, vol. 1, no. 2, pp. 1–7, 2021.

[102] S. S. Gill *et al.*, "AI for next generation computing: Emerging trends and future directions," *Internet of Things*, vol. 19, p. 100514, 2022.

[103] R. Buyya *et al.*, "A manifesto for future generation cloud computing: Research directions for the next decade," *ACM computing surveys (CSUR)*, vol. 51, no. 5, pp. 1–38, 2018.

[104] C. Chase, "The data revolution: Cloud computing, artificial intelligence, and machine learning in the future of sports," *21st century sports: How technologies will change sports in the digital age*, pp. 175–189, 2020.

[105] U. A. Butt *et al.*, "A review of machine learning algorithms for cloud computing security," *Electronics (Basel)*, vol. 9, no. 9, p. 1379, 2020.

[106] S. Achar, "Adopting artificial intelligence and deep learning techniques in cloud computing for operational efficiency," *International Journal of Information and Communication Engineering*, vol. 16, no. 12, pp. 567–572, 2022.

[107] M. R. Belgaum, S. Musa, M. Alam, and M. S. Mazliham, "Integration challenges of artificial intelligence in cloud computing, Internet of Things and software-defined networking," in *2019 13th International Conference on Mathematics, Actuarial Science, Computer Science and Statistics (MACS)*, IEEE, 2019, pp. 1–5.

[108] S. Wang, Y. Hou, X. Li, X. Meng, Y. Zhang, and X. Wang, "Practical implementation of artificial intelligence-based deep learning and cloud computing on the application of traditional medicine and western medicine in the diagnosis and treatment of rheumatoid arthritis," *Front Pharmacol*, vol. 12, p. 765435, 2021.

[109] J. Agbaegbu, O. T. Arogundade, S. Misra, and R. Damaševičius, "Ontologies in cloud computing—review and future directions," *Future Internet*, vol. 13, no. 12, p. 302, 2021.

[110] A. Taherkordi, F. Zahid, Y. Verginadis, and G. Horn, "Future cloud systems design: challenges and research directions," *IEEE Access*, vol. 6, pp. 74120–74150, 2018.