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(Review Article)

A review on cloud computing-based quality assurance: Challenges, opportunities, and best practices

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Abstract

There are many parts of software development and deployment that have been transformed by cloud computing, one of which is quality assurance (QA). The use of cloud computing into quality assurance procedures provides enterprises with numerous benefits, including flexibility, scalability, and efficiency, which in turn enables them to more efficiently guarantee the quality of their software products. The fundamental objective of this study is to determine what components of cloud computing QA are most crucial. More specifically, the research will concentrate on the identification and analysis of key quality parameters. Specifically, the study highlights the distinct quality assurance issues and requirements that are associated with each cloud computing model by analyzing a variety of cloud computing models, such as SaaS, PaaS, and IaaS. Further, the work discusses potential future directions in cloud quality assurance including automation and multi-cloud approaches and how these directions might be applied to improve the quality assurance processes. One more contribution of the study is that it reveals critical challenges that quality assurance teams face when operating in cloud environments and discusses the possibility of enhancement through the use of innovative technologies. In result, a collection of best practices to facilitate efficient quality assurance in cloud environments is provided. The purpose of this set of practices is to optimize quality assurance procedures, reduce costs, and guarantee the delivery of high-quality cloud services.

Keywords: Cloud Computing (CC); Challenges; Quality Assurance (QA); Opportunities

1. Introduction

Cloud computing is a developing concept that is used in distributed computing and grid computing environments, with distinct characteristics [1]. Cloud computing is a rapidly developing platform that offers web-based services. The service encompasses a variety of on-demand services and requests, ensuring the highest level of quality for consumers of CC. A widespread use of CC by many organisations has resulted in the identification of several restrictions. Security, reliance, privacy, and quality of service (QoS) remain significant obstacles to an adoption of cloud services. Remote and on-demand access to resources is made possible with cloud computing. Virtualisation is a state-of-the-art technology that enables us to maximise use of electricity. Virtual machines may be hosted on a single server system. This strategy involves reducing the power consumption of servers while they are not actively doing tasks. When discussing non-ration, it is often referred to as server capacity [2].

The following are some of the unique features of big data applications as compared to more conventional ones: (a) computational statistics based on massive amounts of diverse data in both structured and unstructured formats; (b) evolution of knowledge-based systems and machine learning; (c) intelligent decision-making in the face of uncertainty; and (d) needs for more complicated visualisations. Innovative quality assurance methods are required to guarantee the accuracy of these new big data application functionalities [3]. For instance, big data applications include a great deal of unstructured data in contrast to data in conventional applications (graphical, image, sound, document, etc.). The data in

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question is often disparate and unstructured. Especially in performance testing, conventional testing procedures do not account for testing methodologies for large-scale data since such data processing is not necessary in conventional applications [4][5].

1.1. How to Assurance Cloud Quality?

The functionality of a cloud network is significantly influenced by its quality. As it becomes more important, cloud service providers must be certain that the end customer will get the high-quality cloud they need. Users get significant administrative and operational advantages from cloud quality assurance, and in certain situations, it becomes an obligatory step when users employ the Internet or public clouds. The reason for this is because resources and services in public clouds are made publicly, freely, and regularly accessible. Secondly, it is almost impossible to manage cloud quality in public clouds. A potential solution to this problem is to create a private cloud that offers public cloud services and virtualisation [6].

In the long run, consumers will be enticed to use cloud computing networks due to the cost reductions that come from combining cloud quality with availability, performance, security, and privacy. Cloud quality parameters are grouped and shown in Figure 1.

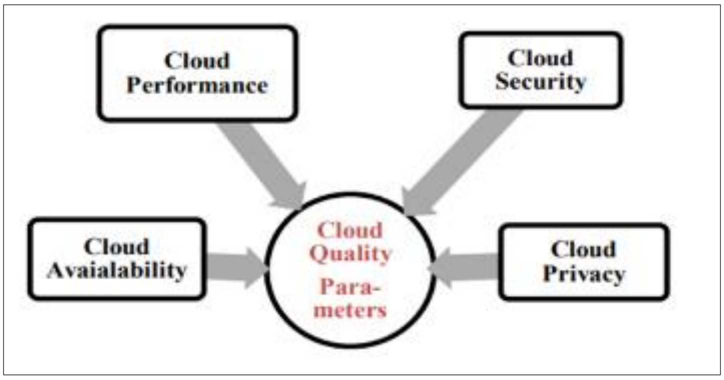

Figure 1 Cloud Quality Parameters

Cloud availability is a crucial factor that assures the availability of cloud services whenever they are needed and without delay[7]. The quality of a cloud is directly proportional to this. The capacity of a cloud service to continuously provide dependable and uninterrupted access to its resources and services is referred to as high availability. Cloud security and privacy are concerned with safeguarding and maintaining the privacy of the information, resources, and services that cloud service users utilise. Cloud Quality Assurance aims at satisfying the privacy and security requirements of clients, end users, service consumers, and stakeholders. The quality of a cloud service depends upon several parameters, such the state of other structures, the intensity of Internet traffic, effectiveness of particular applications, safety of stored data and probability of service breakdowns [8].

The objective of this work is to expand a knowledge of QA in cloud computing studies discussing the issues, potentials, and innovation of the area. The impetus for this work arises out of necessity, to tackle these issues and give a proper review of how exactly one can enhance QA for cloud computing. Consequently, this article aspires to make a contribution to the ongoing progress and widespread adoption of cloud solutions while also ensuring the integrity and safety of the services provided to customers. The paper contributed as:

- Discusses parameters such as availability, performance, and security noting their effects on cloud service dependable performance.
- Explores QA requirements for SaaS, PaaS, and IaaS models, offering insights for providers and users.
- Highlights challenges like scalability and security, while proposing opportunities for improvement through automation and big data analytics.
- Recommends best practices to optimise QA, reduce costs, and ensure high-quality cloud services.

1.2. Structure of the paper

The following paper structure as: This paper begins with an Introduction to cloud computing and quality assurance with contribution discussed in Section I. Cloud Computing Architecture with Models in Section II. Quality Assurance in Cloud details QA principles and benefits in Section III. Challenges and Opportunities addresses issues and prospects in cloud

QA in Section IV. Literature Review summarises existing research in Section V. Future Trends explores emerging trends in Section VI. Conclusion wraps up the key insights and recommendations in Section VII.

2. Cloud Computing Architecture with Models

Cloud computing offers the convenience of delivering and paying for consumption services on demand over the internet. Cloud computing services include a wide variety of offerings, including whole apps, servers, infrastructure, and storage. Cloud services are categorised into three types: The term "cloud computing" refers to three distinct service models. The first is SaaS, where a software is operated and managed by the software provider. The second model is known as IaaS, and it involves a provider offering storage and networking services to other businesses. A third is PaaS, which offers both software and hardware resources for building a cloud platform[9].

2.1. Types of Cloud-Based QA Services

The following cloud services as:

- **SaaS, or software as a service,** is a model for delivering, managing, and maintaining software applications, operating systems, and other resources. A user accesses the cloud by means of an application developed and maintained by the cloud provider. Some examples of SaaS providers include Google Apps, Gmail, Salesforce CRM, Lotus Live, and Sales Force. Delivers software applications over the cloud, enabling teams to perform QA without worrying about hardware or software maintenance[10].
- **Platform as a Service (PaaS)** refers to a service layer where a provider manages and offers various resources. Applications built using a variety of languages and technologies may be deployed into the cloud infrastructure by the user. The cloud provider, such Aptana, Windows Azure, Google App Engine, or force.com, is responsible for maintaining these technologies. Offers a platform that supports the entire application lifecycle, including development, testing, and deployment, without managing the underlying infrastructure.
- **Infrastructure as a Service (IaaS)** refers to a level of service where a supplier offers virtual resources, like data storage, processing capabilities, and bandwidth, in a cloud environment. A wide variety of programs, including system and application software, are available for users to install and launch. Companies like Akamai, Amazon EC2, and DropBox are among the many IaaS providers. Provides virtualised computing resources over the internet, allowing QA teams to set up and manage their testing environments.

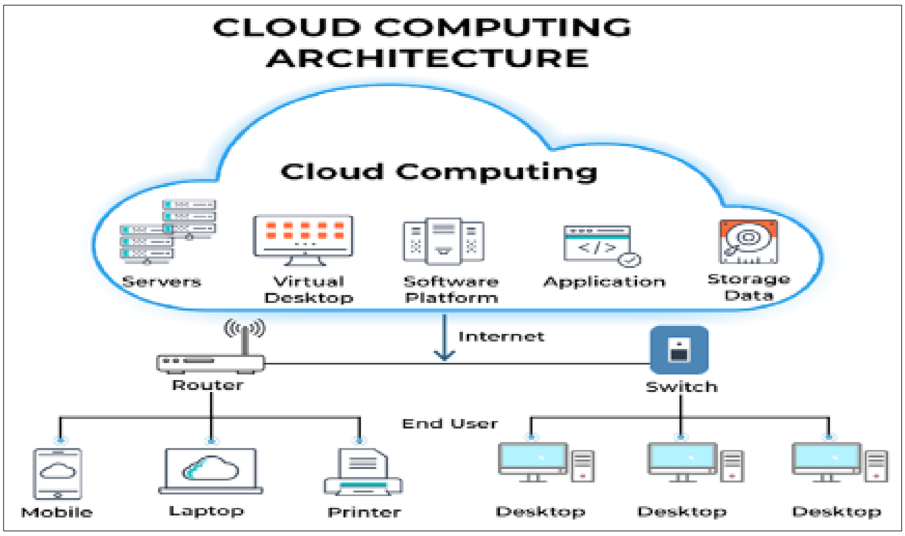

Figure 2 Architecture of Cloud Computing

Figure 2 depicts a fundamental structure of a CC system. This infrastructure exhibits several levels of resources and service providers. Numerous deployment options are accessible for individual cloud services, independent of the cloud services paradigm [11]:

- **Public Cloud:** The service provider hosts and manages the infrastructure in the public cloud. The cloud user cannot see the cloud or exert any influence over it. The public may utilise cloud architecture at a minimal cost.

Infrastructure in the public cloud has the advantage of being highly vast and scalable, allowing for the addition of various value-added services to improve the network.

- **Private Cloud:** A single user may operate and administer a private cloud system. The network that cloud users may access is owned by the association. Only a certain group has access to the cloud structure. Community Cloud: Many organisations employ this cloud structure, which is tailored to a particular community.
- **Hybrid Cloud:** A combination of public and private clouds, or even just two clouds, is one way to describe this cloud architecture. Although the hybrid cloud under this structure has unique entities, it also uses proprietary and standardised technologies to ensure data and application compatibility. The difficulties with cloud computing are shown in Figure 3.

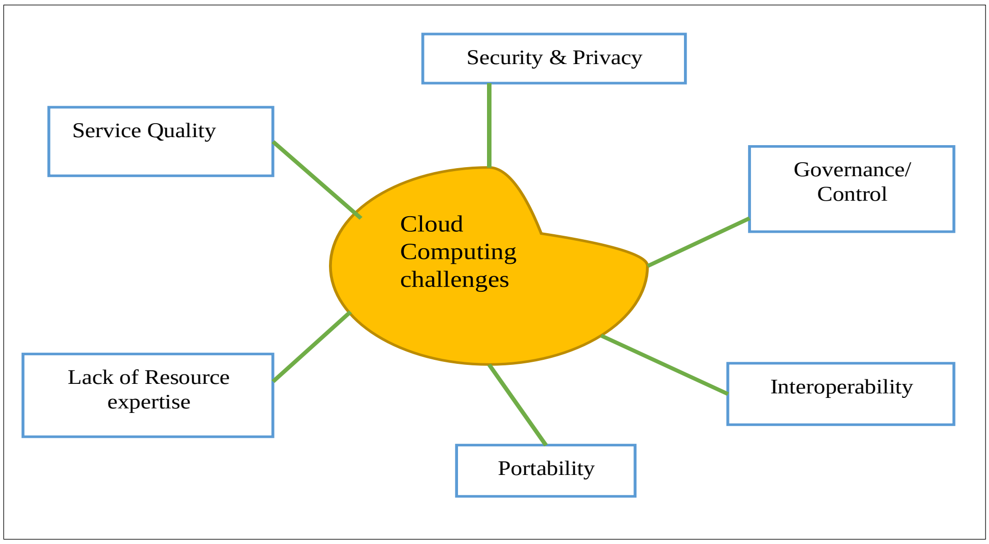

Figure 3 Cloud Computing challenges

Cloud computing has revolutionised business operations and consumer digital services. The cloud's scalability, cost-effectiveness, and accessibility allow companies to focus on their strengths while using powerful computing capabilities. However, cloud computing's rapid growth and widespread adoption have brought unique challenges. In today's digital environment, companies face major challenges while embracing cloud computing[12].

2.2. Future Trends in Cloud-Based QA

- **AI and Automation:** It is anticipated that cloud-based QA would test more accurately and efficiently when AI and automation technologies are integrated.
- **DevOps and Continuous Testing:** Continuous integration and delivery (CI/CD) pipelines are supported by cloud computing, which makes it easier to do continuous testing and distribute software more quickly.
- **Multi-Cloud Strategies:** Organisations are rapidly adopting multi-cloud strategies to use the benefits provided by many cloud providers for QA.

3. Quality Assurance in Cloud

The term "quality assurance," sometimes abbreviated as "QA," describes the processes that manufacturers use as part of a quality management system to guarantee that their goods consistently meet or exceed customer expectations. Quality assurance, which is often used in conjunction with quality control, is a component of the ecosystem that ensures customers obtain high-quality products free of incidental flaws. Manufacturers control product quality by testing, not through quality verification [13]. All industrial settings need quality assurance, but certain industries need it more than others—the automobile sector, for example, and suppliers of very accurate parts—because dropping the ball on maintaining a high standard of quality might cost lives[14]. The concept of quality assurance was first presented as a methodical approach in the manufacturing sector, and it has subsequently expanded to several other sectors, including computer programming [15]. A company may benefit from quality assurance if it uses it to provide goods and services that meet or exceed customer expectations. It creates high-quality product choices that win the confidence and devotion of consumers. Preventing future product failures is one of the main goals of a QA program [16].

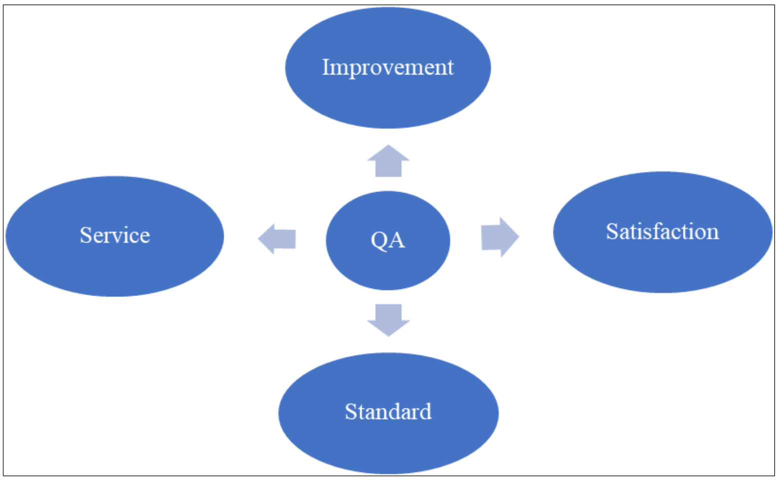

Figure 4 Quality Assurance [16]

The purpose of quality assurance is to systematically check whether a product or service meets certain criteria. The purpose of quality assurance is to set and maintain standards for processes that are either developed or produced. Companies may get an advantage over their rivals by implementing a quality assurance system, which boosts productivity, customer trust, and the firm's reputation (Figure 4).

3.1. Benefits of Quality Assurance

There are many advantages for firms that prioritise quality assurance. Here are three advantages of quality assurance that are emphasised in[17][16]:

- **Cost Savings:** QA plays a crucial role in avoiding quality problems as it is an active part of quality management. Because there is less need to handle returns, waste, and other consequences of subpar goods, manufacturers may save a significant amount of money.
- **Efficiency Boosts:** Companies may save time, money, and warehouse space by making more high-quality components, and they can use that savings toward other successful efforts that involve fewer faulty items. With systems in place to guarantee their success, producing high-quality items uses fewer resources.
- **Improvements in Customer Satisfaction:** The application of efficient quality assurance systems by producers leads to more consistent, superior goods, shorter production periods, and better quality for consumers. There will be more people to do these tasks, which means that in the future, customers will have more options for personalization and innovation and less likelihood of getting a subpar product.

3.2. Quality Assurance Methods

Quality assurance is accomplished using one of three methods [16]:

- Performing frequent tests to identify product failures is known as failure testing. Products made of physical materials that are expected to withstand stress often need to be tested in conditions of high heat, pressure, or motion. The failure testing method for software products may include subjecting them to severe load or high-use tests.
- Walter Shewhart worked at Southern Electric and Bell Telephone Laboratories in the 1920s and 1930s to create the statistical process control (SPC) approach. Accurate facts and analysis back it up. This enables the management of the manufacturing process by use of statistical techniques.
- TQM or total quality management provides the foundation for the continual advancement of improvement with the introduction of quantitative techniques. The TQM system utilises the facts and data pertinent to the evaluations of the products and the plans involved.

4. Challenges and Opportunities of Cloud Computing-Based Quality Assurance

This section looks at the problems, opportunities and best practices in quality assurance of cloud computing services. The issues raised here are of concern, and the best practices as well as the challenges are discussed here.

4.1. Challenges

Cloud infrastructures are dynamic and complex and, therefore, make cloud computing QA challenging. The fluidity of cloud systems' infrastructure also poses a problem. The cloud infrastructures are likely to provide faster provisioning, de-provisioning and scalability of resources as compared to conventional IT implementations. Frequent occurrence of this phenomenon can complicate the reproducibility of testing environment or inability to consistently reproduce a defect. Another test type is also a challenge and it is called scalability testing. Cloud-deployed apps are conversely required to have dynamic scalability in relation to varying loads, which is difficult for conventional QA methodologies to validate. Balancing between achieving application scalability in the cloud environment and its performance and reliability is a challenging task and this means that there is a need for testing tools and techniques. Security issues are also a problem. Multi-tenancy and a shared tenancy model for cloud implementation leads to challenges in data security, user permissions and vulnerability maintenance. Apart from application security, SCA also has to address underpinning infrastructures and platforms. Lastly, it is essential to control costs. Testing, particularly complex or multiple simulations or long test runs, may be expensive in CC, which is provided on a pay-as-you-go basis. Another key challenge of cloud-based quality assurance team therefore lies in finding ways to manage tests effectively across resource expenses to ensure that quality is not compromised through budget limitations. Some of the risk that come with cloud computing.

4.2. Opportunities

QA is also one of the areas where cloud computing provides many opportunities for getting better and changing testing and quality management. Automation offers great potential. Hence, the automation testing frameworks have the ability to include it in CI/CD pipeline system in cloud environment. It enables the fast implementation of tests, standardised testing flows, and efficient distributed testing to minimise the time taken to validate software releases. Another possibility is timely availability of test environments as and when required. Cloud computing allows QA teams to easily create and delete test mechanisms that mimic production conditions without purchase of hardware and software. This strategy makes testing faster because businesses can test in many configurations and then dismantle the environments. Cross-platform refers to testing the program on different operating systems, browsers, and other devices available on cloud platforms. QA manages to review other operational conditions, and the compatibility of applications with the tested program, enhancing its quality. Another area where there is potential for use of big data analytics is quality assurance. Cloud platforms usually come equipped with strong analytics capabilities that allow the analysis and analysis of a large amount of test data. QA teams use these to assess the performance of applications, find problems soon enough and enhance testing procedures. Analytics-based approaches enhance decision-making and software quality, thus making cloud computing a significant aid in the latest quality assurance.

4.3. Best Practices

Optimal cloud roles and responsibilities for QA are always important in enhancing efficiency and minimising hindrances. Continuous testing is a must and preferable. When there are constant and fast-changing cloud systems, integrating testing into the CI/CD pipeline makes certain that the code modifications are automatically tested. The continuous testing system locates problems in the gears before the production process and quenches possible bugs that may come along. Another brilliant practice is the comprehensive security testing. Cloud installations are multiple-user situations; therefore, security testing is a critical optimisation factor. This includes vulnerability scans and assessments, penetration tests, and compliance with applicable security standards and laws.

Safety measures of quality assurance can protect cloud-based apps through the enhancement of security features. It is also necessary to define strategic approaches to cost regulation. Quality assurance teams should strategically organise tests during low demand, use cost-effective cloud services, and continuously monitor their financial impacts to maximise cloud resource use. Testing cost management solutions are essential to avoid cloud computing's benefits being swamped by excessive expense. Additionally, use cloud-native tools and services. Cloud-native quality assurance solutions automate scalability, monitoring, and integration with other cloud services to work smoothly in cloud environments. These solutions improve quality assurance, allowing companies to make use of cloud computing while maintaining high software quality standards.

5. Literature Review

This section offers an overview of the research on quality assurance in the cloud. Several literature reviews are described in detail in this section.

In, Arora and Gupta, (2023) takes a look at a strategy for automating quality assurance using cloud computing. As a result of cloud computing's explosion in popularity over the past many years. An growing number of companies are contemplating using a quality system that is hosted in the cloud for quality management purposes. Consequently, this research has introduced a cloud-based, ML-algorithm-based visual quality assurance proposal system. Response latency and the accuracy of manufacturing component fault detection are used to assess the model. Approximately 8 seconds was determined to be the average reaction latency, and the model had an average accuracy of around 93%[18].

In, Abdelmaboud et al., (2015) to conduct an assessment of the state of the art regarding CC's QoA techniques in order to determine areas that both present and future research initiatives should prioritise. Following a methodical mapping investigation to identify relevant literature, 67 publications were chosen as main studies and categorised according to the topic, research kind, and contribution type. The validation research type comprises the bulk of the papers (64%). The majority of the study was centred on IaaS (48%), with SaaS (36%). Models accounted for 32% of the total contributions, while techniques accounted for 48%[19].

In, Veloudis et al., (2014) showcases a framework's conceptual design that addresses virtual organisations' needs for optimisation and quality assurance in cloud services. Optimisation, failure prevention and recovery, and quality control and governance are the three overarching concepts of the framework. Consequently, their IT landscape is evolving into a complex ecosystem of interdependent platforms, applications, and infrastructure services[20].

In, Lee et al., (2012) The researchers in this study developed an enterprise cloud computing middleware that safeguards and efficiently accesses cloud services while also automatically managing the distribution of resources across platforms, infrastructures, and services. Agent technology was employed to monitor the requested QoS requirements and Service Level Agreement; this technology is capable of supporting Verification and Validation, as well as dynamically analysing resource allocation and deployment. The goal was to provide complete transparency of the underlying technology and the environment, making testing and management easier[21].

This study, Jain, Singh and Singh, (2013) examines the structure and components utilised in cloud verification. Cloud engineering employs procedures to design a cloud network. Quality assurance and verification are essential to progress. Cloud network quality and web service are assured by quality assurance. Cloud Verification is essential to network economic cloud computing solution development. Compare the terms, conditions, and requirements of the service level agreement with the performance, flexibility, availability, dependability, and security of the cloud network. This article examines quality-affecting Quality Assurance factors and metrics[22].

This Table 1 summarises the related works by categorising their methodologies, achievements, limitations, and proposed future work, providing a clear overview of the current research landscape in cloud computing-based quality assurance.

Table 1 Summary of the related work for cloud-based quality assurance

Reference	Methodology	Achievements	Limitations	Future Work
[18]	Service-based system for visual quality assurance using machine learning algorithms and CC.	Achieved approximately 93% accuracy in defect detection with an average response delay of ~8 seconds.	Limited response delay and accuracy metrics, not covering scalability or robustness in diverse environments.	Explore improvements in scalability and reduction of response delay for broader industrial application.
[19]	Systematic mapping study of QoA approaches in cloud computing.	Identified 67 primary studies, classified by focus, research type, and contribution type; majority focused on IaaS and SaaS with methods as the main contribution.	Limited exploration of emerging trends and newer technologies within QoA in cloud computing.	Investigate newer cloud services and technologies, and their implications for QoA approaches in future research.
[20]	Conceptual architecture for quality assurance	Provided a framework addressing governance, quality control, failure prevention,	Mainly theoretical; lacks empirical validation and detailed	Implement and validate the proposed framework in real-world

	and optimisation in virtual enterprises.	recovery, and optimisation in cloud services.	implementation strategies.	scenarios to assess its effectiveness.
[21]	Middleware for automatic resource allocation in Enterprise Cloud Computing using agent technology.	Enhanced transparency and ease of management/testing; supports dynamic resource allocation and SLA monitoring.	Focused primarily on resource management; limited discussion on security and cost-effectiveness.	Explore integration with advanced security mechanisms and cost-optimization strategies.
[22]	Examination of quality assurance factors and metrics in cloud verification and engineering.	Highlighted the importance of QoA in cloud verification, emphasising performance, reliability, and security.	Limited practical examples or case studies to support theoretical discussions.	Develop case studies and practical applications to validate the identified QoA factors and metrics.

6. Future Trends in Cloud-Based Quality Assurance (QA)

The following research areas are future trends in cloud-based quality assurance:

- **AI and Machine Learning Integration:** Automating quality assurance procedures in cloud environments will rely heavily on AI and ML [23]. These technologies can be used for predictive analysis, anomaly detection, and self-healing mechanisms, leading to more efficient and proactive QA practices[24].
- **Cloud-Native Testing Tools:** As cloud-native architectures become more prevalent, there will be a rise in the development and adoption of cloud-native testing tools. These tools will be designed specifically to handle the complexities of microservices, containerisation, and serverless computing, ensuring that QA processes are well-suited to modern cloud environments[25].
- **Continuous Testing in DevOps:** Continuous testing will become more integral to DevOps practices in CC. With an increasing need for rapid deployment and frequent updates, QA processes will need to be fully integrated into the CI/CD pipeline, enabling real-time testing and feedback[26].
- **Multi-Cloud and Hybrid Cloud QA:** As organisations adopt multi-cloud and hybrid cloud strategies, QA processes will need to evolve to handle the complexity of testing across multiple cloud platforms. This includes ensuring compatibility, security, and performance consistency across different cloud environments.
- **Security and Privacy Testing:** With growing concerns around data security and privacy, especially in regulated industries, there will be a greater emphasis on testing for compliance with security standards and data protection regulations. Advanced security testing tools and techniques will be developed to address these concerns in cloud-based environments[27].

7. Conclusion

Cloud computing is a relatively new field that will eventually play a significant part in everyone's life, but in order to get there, cloud quality assurance is necessary. There are several requirements and elements that must be followed in order to guarantee quality. This article concludes with an in-depth examination of the key quality metrics and difficulties of cloud computing quality assurance. The study has highlighted the unique QA requirements for different cloud models and examined the potential of emerging trends such as AI and automation to enhance QA processes. By identifying the key challenges and opportunities within cloud-based QA, this work contributes valuable insights for both cloud service providers and users. The proposed best practices offer a practical approach to optimising QA processes, ensuring high reliability and performance of cloud services while addressing the dynamic and scalable nature of cloud environments. This research lays a foundation for future advancements in cloud QA, encouraging further exploration of innovative solutions to meet the evolving demands of cloud computing. Continuous evolution of cloud technology necessitates the adaptation of quality assurance procedures to align with progress in fields like AI, ML, and edge computing. These technologies are positioned to further amplify quality assurance capabilities, facilitating more accurate, effective, and secure testing procedures. Organisations that skillfully utilise cloud computing for quality assurance will be in a favourable position to provide dependable, high-performing, and secure software in a highly competitive and rapidly evolving digital environment.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest is to be disclosed.

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