# A Study of Cloud Security Frameworks for Safeguarding Multi-Tenant Cloud Architectures

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## ABSTRACT

Multi-tenancy in cloud computing allows multiple tenants to share resources efficiently, offering cost-effectiveness and scalability. However, this architectural design introduces complex security challenges, necessitating robust frameworks and strategies to safeguard sensitive data and maintain isolation among tenants. This paper explores multi-tenancy security concerns and solutions, emphasizing data isolation, unauthorized access prevention, and compliance with regulations. Key techniques, such as virtual and organic multi-tenancy and data storage strategies, ranging from separate applications to shared databases, are analyzed. Furthermore, security frameworks such as the Shared Responsibility Model, Identity and Access Management (IAM), data protection mechanisms, and network security are discussed. Advanced technologies, including confidential computing and homomorphic encryption, are highlighted for their potential to enhance security in multi-tenant environments. The paper underscores the importance of addressing tenant isolation, data encryption, compliance requirements, and availability risks to ensure a secure and resilient multi-tenant cloud infrastructure.

## Keywords

Cloud Computing, Multi-Tenancy, Multi-Tenant Architectures, Cloud Security Frameworks, Cloud Infrastructure.

## 1. INTRODUCTION

The development of several technologies since its start has been facilitated by the internet. The paradigm shift towards using cloud computing has been tremendous in recent years [1]. A new paradigm is about to be defined and implemented, and service providers are very interested in the cloud model since it portends enormous revenue potential and the next wave of internet innovation. Cloud computing is an evolution of many earlier technologies, including service-oriented architectures, Grid computing, and utility computing [2] [3]. The usage of cloud computing allows many businesses to expand up without incurring huge costs associated with purchasing new hardware, software, or constructing massive data centers [4][5]. The utilization of hardware, software, and the provision of services to end users is greatly enhanced by cloud computing [6]. Three primary services are essential to a cloud computing architecture [7]: IAAS, SAAS, and PAAS. PAAS provides users with operating systems and platforms, whereas IAAS gives them access to storage and networks. SAAS lets people access software. Cloud systems have front and back ends. The internet connects the user to the front end and the back end, which is the cloud [8][9]. Core middleware provides an application runtime environment and optimizes resource use. The architecture of cloud computing is shown in Figure 1.

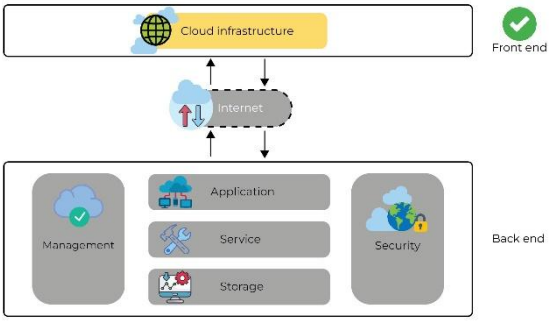


**Fig. 1. Architecture of Cloud Computing**

The new architecture of cloud computing is called multi-tenancy. It makes it clear that in a multitenant architecture, users may tailor the system to their own requirements just as they would in a dedicated environment by sharing hardware resources, applications, and database instances." Hardware services may be shared using multi-tenancy, and a high degree of device customization is available [10][11]. A security compromise might expose data from other tenants in an environment where several tenants use a single database and application instance. Cloud computing's benefits need a paradigm shift, with security being one of the greatest obstacles[12].

The motivation for this paper stems from the rapid growth of multi-tenant cloud architectures, which offer significant benefits such as cost efficiency and resource optimization. However, the shared infrastructure in these environments poses unique security challenges, including data isolation, unauthorized access, and compliance with various regulatory requirements. With organizations increasingly relying on multi-tenant cloud services, it is essential to develop robust security frameworks that address these concerns effectively. The purpose of this article is to examine cloud security frameworks in depth in order to protect cloud architectures that house many tenants. Here are the main points of this paper:

- This paper reviews the security issues specific to multi-tenancy Cloud, such as data segmentation, unauthorized access, resource competition and compliance issues, upon which it lays the groundwork to address those.
- It provides a comprehensive study of current cloud security models and guidelines for multi-tenant environments, adding security layers to prevent data breaches affecting other tenants and enhance resource utilization.
- This work looks at new and more sophisticated solutions, like homomorphic encryption, TEEs and SMPC, that help to enhance security in multi-tenant cloud environments.
- The paper presents recommendations on how the tenant isolation can be enhanced, data encrypted adequately, legal requirements observed, and shared responsibility

models embarked on for increased security of multi-tenant cloud.

The following paper is organized as; Section II provides the overview of multi-tenancy security in cloud computing, Section III discusses the Multi-Tenant Architectures Cloud, Section IV give the cloud security frameworks For Safeguarding Multi-Tenant Cloud Architectures, Section V discusses some Security Concerns in Multi-Tenant Cloud Environments, Section VI provide the Literature Review with comparative table, and last section provide the conclusion and future work.

## 2. MULTI-TENANCY SECURITY IN CLOUD COMPUTING

The ability to use the same set of hardware and software resources by many users is known as "multi-tenancy," and it is made possible by cloud computing. Multi-tenancy is a fundamental characteristic of cloud computing, enabling multiple tenants to share a common cloud infrastructure. While multi-tenancy offers cost-efficiency and resource optimization, it also introduces unique security challenges[13][14]. Multi-tenancy denotes the allocation of computational resources, storage, services, and applications among multiple tenants. The term "multi-tenancy" refers to the practice of allowing many users with varying requirements to share a single application [15]. "Multitenancy" refers to the practice of making one instance of a program (in this case, the cloud) available to several users [16]. Here, every user is referred to as a tenant. To make access to an instance of cloud computing cost-efficient, customers with comparable resource needs are assigned a single instance of the cloud, and the cost is divided among other users[17]. Figure 2 shows the Working of Multi-Tenancy cloud architecture. Using virtual machines, providers in multi-tenant architecture may run several copies of the same hardware on a single server [18][19]. This paves the way for app developers to host an infinite number of concurrent users on several versions of the same app. The data of each tenant is protected since each version is separate and encrypted.

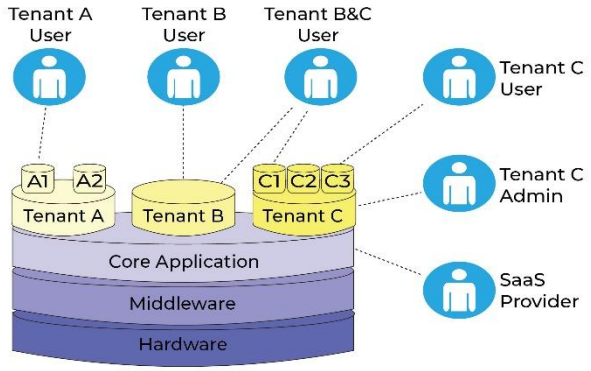


**Fig. 2. Working of Multi-Tenancy Cloud Architecture**

The data stored in a single database that is running on the same operating system may be readily accessed, maintained, configured, and modified with the help of multi-tenancy [20][21]. A crucial approach for executing any kind of service, including IaaS, SaaS, and PaaS, in both public and private clouds is multi-tenancy. IaaS is a common topic of conversation when people talk about clouds. Bypass the IaaS layer and combine it with the PaaS and, finally, the SaaS or application layers for multi-tenancy. IaaS includes things like servers, storage, and networking components; PaaS includes things like application servers, business logic, workflow, databases, and virtual machines (VMs) running Java, such as Java compilers. One may broadly classify multitenancy techniques as either[22]:

- **Virtual Multi-Tenancy:** Shared computing and storage resources are available to many users. Multiple tenants are supported via virtual machines that operate concurrently on top of shared computation and space resources.
- **Organic Multi-Tenancy:** Different tenants own different components of the network architecture in organic multitenancy. On the Internet, multi-tenancy concepts are implemented at three distinct consumer integration rates.

### *A. Challenges in Multi-Tenancy Security*

One of the primary challenges in multi-tenancy is ensuring:

- **Data Isolation:** Tenant data resides on shared physical or virtual resources, raising the risk of accidental exposure or intentional breaches. Without robust measures, it is possible for malicious actors or poorly configured systems to access sensitive information belonging to other tenants.
- **Unauthorized Access:** Weaknesses in access control mechanisms can allow one tenant to gain unauthorized privileges over another tenant's resources, threatening confidentiality and trust.
- **Resource Contention:** Multiple tenants competing for the same resources can lead to performance degradation and side-channel attacks. This is especially problematic in environments where computational and network resources are stretched thin.
- **Compliance and Regulations:** Meeting compliance and regulatory requirements for multiple tenants simultaneously is a challenge. Providers must ensure data residency, protection, and auditing obligations across industries and geographies.
- **Insider Threats:** Employees of the cloud provider may exploit shared infrastructure, posing significant risks to multi-tenant environments. Insider threats require vigilance and effective access monitoring.

## 3. MULTI-TENANT ARCHITECTURES IN CLOUD

A multi-tenant architecture allows for the simultaneous use of several tenants via the provisioning of a single software instance on a server operating on the infrastructure of the service provider. The implementation of SaaS, or software as a service, relies on it. SaaS is becoming more popular, particularly among SMEs. Anyone, any entity who contracts with the multi-tenant SaaS model is referred to as a tenant[23].

### *A. Data Storage Strategy*

Isolated and shared characteristics are described by three data storage strategies. This is seen in Figure 3.

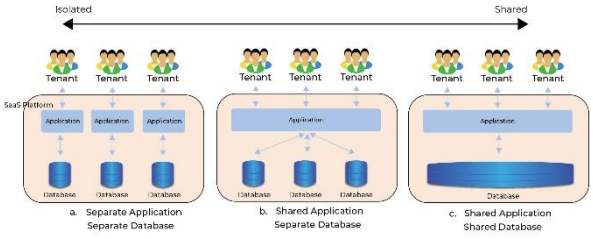


**Fig. 3. Data Storage Strategy**

**Separate Application, Separate Database:** Here, each user has their very own database and program. Every single one of the renters lives in a separate building. The model's inefficient use of system resources and the time and money needed for maintenance and updates are major issues.

**Shared Application, Separate Database:** All of the renters are using a single software program. By the way, every user has their very own physically isolated database. The program may be tailored to each tenant's specific needs by using specialized procedures.

**Shared Application, Shared Database:** A common program is used by the tenants. There are two versions of this vehicle. You may choose between two types of schemas: shared database and separate database. In Figure 4, you can see them.

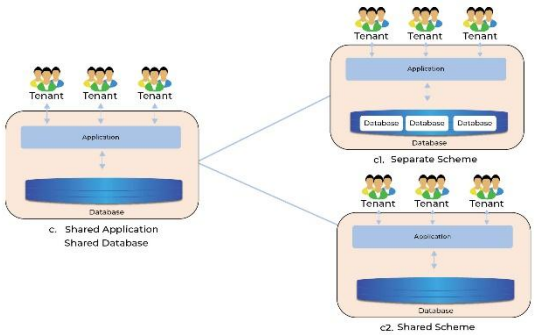


**Fig. 4. Separate Schema*Shared Schema**

**Shared Database, Separate Schema:** Each tenant in this model makes use of its own set of tables inside the shared database. This is seen in Figure 5. It is simpler to deploy and tailor to user demands when individual schemes are designed for each tenant. The main drawback is the need to maintain a high number of tables.

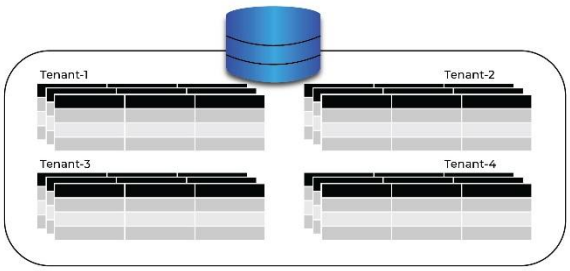


**Fig. 5. Separate Schema**

**Shared Database, Shared Schema:** As seen in Figure 6, this method uses a shared database and schema for all tenants.

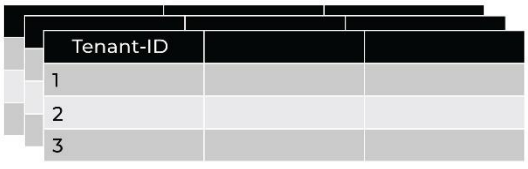


**Fig. 6. Shared Schema**

This strategy maximizes hardware efficiency while minimizing usage and maintenance costs. An issue arises when all tenants are included in the same schema.

*B. Advantages and Disadvantages of a Multi-tenant Architecture*

The benefits of a multi-tenant design are resource efficiency, lower costs, and easier maintenance and updates. Because the whole system is built on the same hardware, any coding error may lead to serious issues with future system administration, and any issue with one tenant can impact all other tenants.

## 4. CLOUD SECURITY FRAME WORKS FOR SAFEGUARDING MULTI-TENANT CLOUD ARCHITECTURES

Multi-tenant cloud architectures allow multiple customers or tenants to share computing resources while maintaining logical separation to protect sensitive data. This architecture provides cost efficiency and scalability but introduces complex security challenges, such as data isolation, access control, and compliance[24][25]. A robust security framework is essential for safeguarding such environments. Below are key cloud security frameworks and best practices tailored to multi-tenant architectures:

*A. Shared Responsibility Model*

In multi-tenant cloud architectures, security responsibilities are shared between cloud providers and tenants. The cloud provider ensures the security of the physical infrastructure, including data centers, servers, and networking hardware. They also direct platform service and ensure tenancy of logical partition between different tenants [26]. However, tenants are expected to secure their applications, data, user identities and access mechanisms on the cloud [27][28]. Such division will avoid situations where one party is failing to contribute while the other party is already working on security issues. One of the major features of this model is to provide and maintain clear understanding of who does what in this model of care.


**Fig. 7. Cloud Shared Responsibility Model**

Figure 7 shows the Cloud Shared Responsibility Model. A variety of cloud models have varied approaches to responsibility distribution, as seen in the accompanying CIS diagram.

B. Identity and Access Management (IAM) Framework

Effective identity and access management (IAM) is critical in safeguarding multi-tenant cloud environments. A Zero Trust Architecture[29] ensures that every access request is verified, regardless of the source or user location[30]. Role Based Access Control (RBAC) reduces risks to their barest minimum, where the user is only given access to those functions that are necessary for him to perform his obligations [31][32]. Multi-factor authentication (MFA) adds another layer of security by requiring additional verification steps. Centralized identity management ensures consistent enforcement of security policies across all tenants and prevents unauthorized access to shared resources[33].

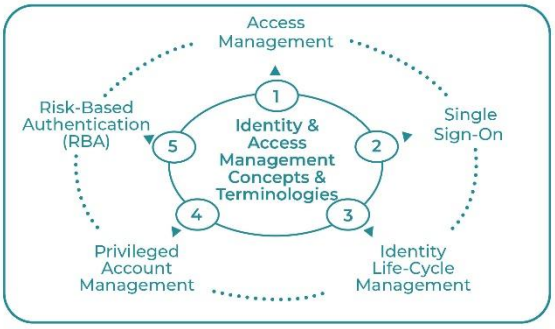


**Fig. 8. Cloud Identity & Access Management (IAM)**

An organization may manage identities, rights, privileges, and access controls with the help of IAM, a subfield of cyber security (see Figure 8).

*C. Data Protection Framework*

Data protection is paramount in multi-tenant systems to prevent data breaches and unauthorized access[34]. Encryption of data both at rest and in transit, using strong algorithms and protocols, ensures its confidentiality[35]. Customer-managed keys (CMK) provide tenants with greater control over their encrypted data. Data masking protects sensitive information by obscuring it for non-privileged users, reducing exposure during data processing[36][37]. Regular backups, coupled with tested recovery mechanisms, ensure data resilience and availability even during unforeseen incidents[38][39].

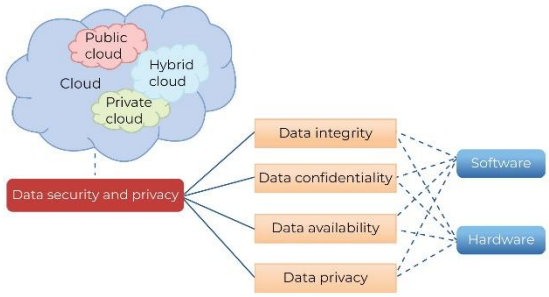


**Fig. 9. Organization of data security and privacy in cloud computing.**

The methods used in cloud computing with regard to data security, as seen in Figure 9, include data availability, confidentiality, and integrity.

*D. Network Security Framework*

Network security ensures that tenants' resources and data remain isolated and protected. Techniques like micro-segmentation allow for fine-grained control by dividing networks into smaller segments, reducing the attack surface[40][41]. Firewalls and Intrusion Detection/Prevention Systems (IDS/IPS) monitor traffic for suspicious activity and block unauthorized access[42][43][44][45]. Virtual Private Clouds (VPCs) enable logical separation of resources with dedicated subnets for each tenant, ensuring secure communication and data isolation. The following Figure 10 shows framework for secure cloud computing.

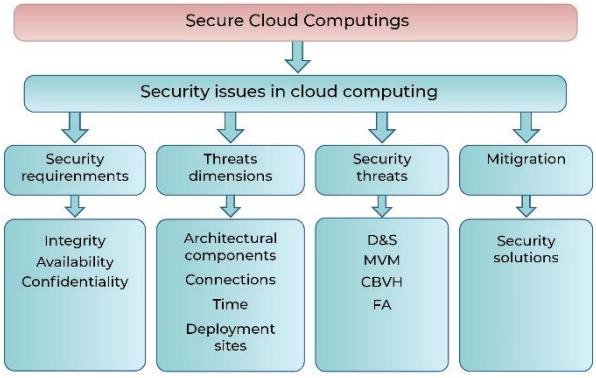


**Fig. 10. Network Security Framework**

*E. Advanced Technologies for Multi-Tenancy Security*

Emerging technologies provide enhanced protection for multi-tenant cloud architectures[46][47]. Confidential computing uses Trusted Execution Environments (TEEs) to secure data during processing, adding an extra layer of security beyond encryption. Homomorphic encryption enables computations on encrypted data without requiring decryption, protecting sensitive information. Secure Multi-Party Computation (SMPC) allows multiple parties to collaboratively process data while preserving privacy, making it particularly useful in shared environments.

## 5. SECURITY CONCERNS IN MULTI-TENANT CLOUD ENVIRONMENTS

The advantages of multi-tenant cloud systems are many, but there are also some dangers and difficulties that come with them. The following are examples of major threats that could arise in cloud settings with many tenants:

- **Data Segregation:** To avoid unauthorized access to sensitive information, it is vital to provide sufficient data segregation. Data leakage or assaults on tenants' data may be prevented by strong isolation techniques that separate tenant data.
- **Tenant Isolation:** To reduce the likelihood of violence amongst tenants, it is essential to maintain strict segregation. Security measures like encryption, network segmentation, and strong access restrictions assist in stopping lateral movement and unauthorized access.
- **Security Compliance:** Cloud infrastructures with many tenants are required to follow strict security regulations, including those of GDPR, HIPAA, PCI DSS, and others. Both CSPs and tenants are responsible for ensuring compliance with regulatory requirements by implementing suitable security controls and policies.
- **Data Encryption:** Protecting sensitive information from unauthorized access or interception may be achieved by encrypting data both at rest and in transit. For the sake of data privacy and security, it is recommended to use robust encryption techniques and implement key management policies[48].
- **Data Residency and Jurisdiction Issues:** Certain geographical areas or countries may be required to store or process data as part of data residency rules. When dealing with several tenants in a building, it may be difficult to ensure compliance with these criteria, especially when tenants are situated in various areas with distinct legal frameworks.
- **Data Loss and Availability Risks:** Tenants in a multi-tenant setting run the risk of serious repercussions in the event of data loss or corruption as a result of hardware malfunctions, software defects, or hostile actions. To

lessen the impact of these dangers, it is crucial to develop reliable backup and recovery procedures and guarantee data availability[49].

## 6. LITERATURE REVIEW

An analysis of the existing literature concerning cloud security frameworks for the purpose of protecting multi-tenant cloud architectures is included in this section. The contents of the literature review on multi-tenant cloud architecture are summarized in Table I, which can be seen below.

In, Shanker et al. (2024) examines cloud forensic challenges and solutions using quantitative methodologies. Major challenges in cloud forensics, including data dispersion, loss of control, multi-tenancy, and integrity/authenticity, were identified. The effectiveness of cloud forensic tools was evaluated, with Tool 2 identified as the most effective. Factors A and B were found to influence tool adoption. Emerging trends in cloud forensics, such as advancements in cloud technologies and new security threats, were explored. The study provides valuable insights for practitioners and researchers, informing decision-making in addressing challenges, selecting tools, and considering future directions in cloud forensics[50].

This paper, Cheng et al. (2024) explores data authorization and access technologies in multi-tenant environments, employing SQL dynamic substitution strategies to ensure fine-grained data authorization control in a multi-tenant environment. Furthermore, through unified registration and management of databases, the solution meets the requirements for database security, integrity, and privacy protection[51].

In, Ahmed and Bobda (2024) isolation technique is carried out by using reconfigurable MoM (Metal-over-Metal) capacitors and switch banks, along with Power Management and Configuration Controller Unit. Implementing a Custom Configuration Memory (CCM) aims to provide a dynamic and customizable solution that allows FPGA designers to selectively interconnect or isolate groups of Configurable Logic Blocks (CLBs). This approach involves the formation of distinct regions within the FPGA, each capable of sourcing power either from a dedicated CMOS isolation power supply or the standard FPGA voltage power supply[52].

In, Karabulut, Awad and Aysu (2023) suggests a better method for controlling access to cloud FPGAs that are used by several tenants. Our system enables the dynamic setup of access control rights, which is a significant improvement over current commercial product. Our proposal outperforms previous academic work that used dynamic configuration and offered three benefits: (i) tenants can share on-chip BRAM resources securely, (ii) deadlocks and incorrect access requests can be resolved, and (iii) latency and throughput can be improved[53].

The study, Bishnoi and Bhuvana (2023) offers a method that encrypts and decrypts input data inside a cloud environment that works for various tenants by using ontology. The procedure comprises developing an ontology relevant to a certain domain in order to classify concepts, properties, and instances of unstructured language. This ontology, built with the help of the Protégé ontology editor, makes it possible to pay as you go to access relevant data stored by cloud service providers[54].

In this article, Moradi, Wang and Zhu (2023) provide methods for learning online that may be used to model and anticipate the performance of programs that run repeatedly on multi-tenant clouds, including online data analytics. Additionally, a method for progressive modelling has been developed, which involves incremental updates to the Regression and Neural-Network models, allowing for improved response to recent changes in resource contention. Have assessed the suggested online strategies for the accuracy of model predictions and related overheads on public and private clouds using 17 typical applications from the PARSEC, NAS Parallel, and CloudSuite benchmarks. Based on the assessment findings, it is possible to achieve average prediction errors below 20% with periodic retraining, even on private clouds with significant and drastically altered resource contention[55].

In a multitenant system, Bharath Babu and Jothi (2022) Data from comparable applications is shared by several clients on a single instance. To enhance storage efficiency and bandwidth, deduplication methods reduce redundant data. Prior to uploading user data to a third-party CS, it should be encrypted using convergent encryption with deduplication methods to ensure its secrecy. Problems with this deduplication approach might arise when user data is considered confidential. This article offered a solution to these problems by suggesting using the blowfish encryption technique for server-side deduplication and dynamic ownership management. This concept is designed to provide tenant block-level deduplication. Improvements in computational storage efficiency and security are offered by the suggested strategy[56].

Table I highlights the diverse approaches and methodologies used to tackle security challenges in multi-tenant cloud architectures.

**Table I. Comparative Summary of Related Work for Multi-Tenant Cloud Securities**

| Reference | Focus Area | Challenges Addressed | Proposed Solution | Key Features | Benefits | Limitations | Future Work |
|---|---|---|---|---|---|---|---|
| Shanker et al., 2024 | Cloud forensic challenges and tools evaluation | Data dispersion, loss of control, multi-tenancy, integrity/authenticity | Quantitative analysis of forensic tools | Identification of effective tools; factors influencing tool adoption | Informs tool selection and future trends | Limited focus on specific forensic tools | Development of standardised forensic methods for diverse cloud platforms. |
| Cheng et al., 2024 | Data authorisation in multi-tenant systems | Data security, integrity, privacy | SQL dynamic substitution strategies | Fine-grained access control, unified database management | Enhanced security and flexibility | Focused on SQL-based environments | Expanding the framework to NoSQL and other database architectures. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ahmed and Bobda, 2024 | Physical isolation in FPGA-based clouds | Remote physical attacks | Reconfigurable MoM capacitors and switch banks | Spatial tenant isolation, Custom Configuration Memory | Prevents voltage attacks, high security | Limited to FPGA-based architectures | Exploring scalability and integration with non-FPGA-based cloud systems. |
| Karabulut et al., 2023 | Access control for multi-tenant FPGAs | Secure resource sharing, deadlocks, latency | Improved dynamic access control | Secure BRAM sharing, reduced latency and throughput improvement | Enhanced FPGA utilisation and performance | Focus on FPGA without addressing external threats | Investigating compatibility with heterogeneous cloud environments. |
| Bishnoi and Bhuvana, 2023 | Ontology-based encryption for multi-tenancy | Data encryption and categorisation | Ontology with Protégé editor for encryption | Field-specific ontology, pay-per-use cloud model | Streamlined data encryption and retrieval | Relies on accurate ontology creation | Automating ontology creation and extending it to other unstructured datasets. |
| Moradi et al., 2023 | Online learning for resource contention | Prediction under dynamic resource contention | Progressive Regression and Neural-Network models | Adaptive to resource changes, reduced prediction errors | High accuracy in dynamic cloud environments | Periodic retraining adds computational overhead | Incorporating federated learning for better scalability and privacy. |
| Bharath Babu and Jothi, 2022 | Deduplication with user data confidentiality | Redundant data, privacy, deduplication issues | Dynamic ownership management with Blowfish encryption | Tenant block-level deduplication, computational efficiency | Improved storage and data confidentiality | May face scalability issues with large datasets | Enhancing deduplication techniques to support multi-cloud environments. |

## 7. CONCLUSION AND FUTURE WORK

Indeed, multi-tenancy is a double-edged sword when it comes to cloud computing. Data integrity, privacy, and compliance must be guaranteed despite the fact that multi-tenancy in cloud computing allows efficient resource utilization, which presents substantial security problems. Implementing robust security frameworks tailored to multi-tenant architectures is vital. The Shared Responsibility Model delineates roles between cloud service providers (CSPs) and tenants, ensuring collaborative security efforts. Techniques like IAM, encryption, and network segmentation effectively mitigate risks such as unauthorized access and data breaches. Emerging technologies, including confidential computing and secure Multi-Party Computation, provide innovative solutions for securing sensitive data in shared environments. This study highlights that while multi-tenant cloud environments are cost-effective and scalable, achieving optimal security requires ongoing vigilance, advanced technologies, and adherence to regulatory standards. By addressing identified concerns, organizations can fully leverage the benefits of multi-tenancy while minimizing associated risks.

They can reduce the likelihood of data breaches in the future by using data loss prevention systems to efficiently isolate tenants in security models that include more than one tenant. Sharing data might also be a security hole in your multi-tenant architecture, allowing hackers to get sensitive. information. Incorporate controls for collaboration that allow for the monitoring, management, and identification of granular permissions of shared documents. There may be a security risk with the most popular method of managing many complicated rights in your multi-tenant software architecture. Overspending on certain accounts' rights may happen when there are a lot of them, long membership tenures, resources, and service permissions. Some of the greatest offerings include AWS organizations and Azure management groups.

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