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Cloud Architectures for Distributed Multi-Cloud Computing: A Review of Hybrid and Federated Cloud Environment

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Abstract

The concept of several clouds has greatly extended the use of cloud computing and gained popularity in academic and business circles. The use of multi-cloud techniques has increased as businesses use cloud computing more and more to meet their computational demands. A thorough analysis of cloud architectures intended for distributed multi-cloud computing is presented in this study, with an emphasis on federated and hybrid cloud systems. The study looks at the opportunities and difficulties of adopting and overseeing a variety of cloud resources from several providers. The review starts out by going over the basic ideas and reasons for using multi-cloud strategies, emphasizing how important flexibility, scalability, and resilience are in contemporary computing settings. The study then explores the nuances of hybrid cloud architectures, with a focus on how private and public cloud resources can be seamlessly combined. In the context of hybrid cloud installations, important factors including data sovereignty, security, and workload orchestration are covered. In addition, the research delves into federated cloud architectures, clarifying how enterprises can coordinate and oversee workloads across several cloud providers. An examination of resource identification, policy enforcement, and interoperability procedures sheds light on the intricacies of federated cloud computing. The review delves into new developments in standards, best practices, and technology that help multi-cloud ecosystems mature. The study analyses the state of research and industry practices now, pointing out gaps and possible directions for future development. The intention is to provide decision-makers, researchers, and practitioners with a comprehensive grasp of the changing cloud architectural scene so they can plan and execute distributed multi-cloud solutions with knowledge. In conclusion, this article provides a thorough overview of hybrid and federated cloud architectures by combining information from many sources. Through a comprehensive analysis of the difficulties and possibilities associated with multi-cloud computing, the study hopes to add to the current conversation on cloud environment design and optimization in the rapidly changing technological landscape.

A. Introduction

The search for the best solutions for distributed multi-cloud setups has become critical in the rapidly changing world of cloud computing. Businesses are realizing more and more that in order to satisfy the various needs of contemporary business operations, they want cloud infrastructures that are durable, scalable, and flexible [1]. This paper explores the complexities of cloud architectures, with a particular emphasis on federated and hybrid cloud environment assessment [2] [3]. To observe the first celebration of venturing into the broad world of cloud computing, it is imperative that we consider the developments and breakthroughs that have influenced the conversation. At the heart of these talks is the integration of federated and hybrid cloud models, which provide a flexible way to handle the challenges posed by multi-cloud deployments [4]. We start by delving into the complexities of hybrid cloud architectures, where combining public and private clouds with on-premises infrastructure makes a strong argument for increased adaptability and resource efficiency. We break down the essential elements, advantages, and drawbacks of hybrid cloud configurations, illuminating how they can be used in a variety of sectors [5]. Moving forward, the investigation also includes federated cloud settings, in which a number of cloud service providers work together to provide a single computing platform [6]. In addition to reducing vendor lock-in, this cooperative strategy gives businesses the capacity to easily capitalize on the advantages of many cloud providers [7]. In this thorough analysis, we explore the crucial factors that businesses need to take into account when deciding between federated and hybrid cloud architectures. We examine the complex interactions among data governance, security standards, interoperability, and performance optimization, highlighting their subtleties [8].

Furthermore, the paper evaluates hybrid and federated cloud installations objectively, highlighting success stories, real-world applications, and potential hazards. We hope to give readers useful insights and a sophisticated grasp of the potential and difficulties brought about by these cutting-edge cloud models by utilizing a variety of use scenarios. Finally, this article is proof of how quickly technology is developing and how important it is for businesses to be on the cutting edge of cloud invention. Come explore the layers of federated and hybrid cloud systems with us as we search for the most reliable and efficient solutions for the digital age [9].

B. Background Theory

B.1. Cloud Computing

Since computing through the cloud offers adaptable and on-demand processing and storage capabilities, it has completely changed the way enterprises run. This enables companies to grow without having to make huge expenditures in infrastructure or hardware [10]. Through the internet, businesses can now readily access and use networking, storage, and processing power, doing away with the need for physical servers and saving money on upkeep. Moreover, cloud computing provides better collaboration features and increased data security and protection [11].

Because organizations can now concentrate on running their core operations rather than maintaining complicated IT infrastructure, productivity and efficiency have grown. Because cloud computing provides instantly available and adaptable computer and storage resources, it has completely changed the face of business [12]. Nowadays, companies can use cloud computing to cut expenses, improve efficiency, and obtain a competitive advantage. Because cloud computing offers flexible and on-demand processing and storage capabilities, it has completely changed the way business's function [13]. This enables companies to grow without having to make large investments in infrastructure or hardware. With scalable resources that are easily altered based on workload, businesses are able to quickly adjust to changing needs and demands [14]. The move to cloud computing has also made technology more accessible to startups and smaller companies by giving them access to the same resources and processing capacity that larger corporations have. Because the cloud service provider assumes responsibility for managing and maintaining IT infrastructure, cloud computing also gives businesses the chance to concentrate on their strategic ambitions and core capabilities [15].

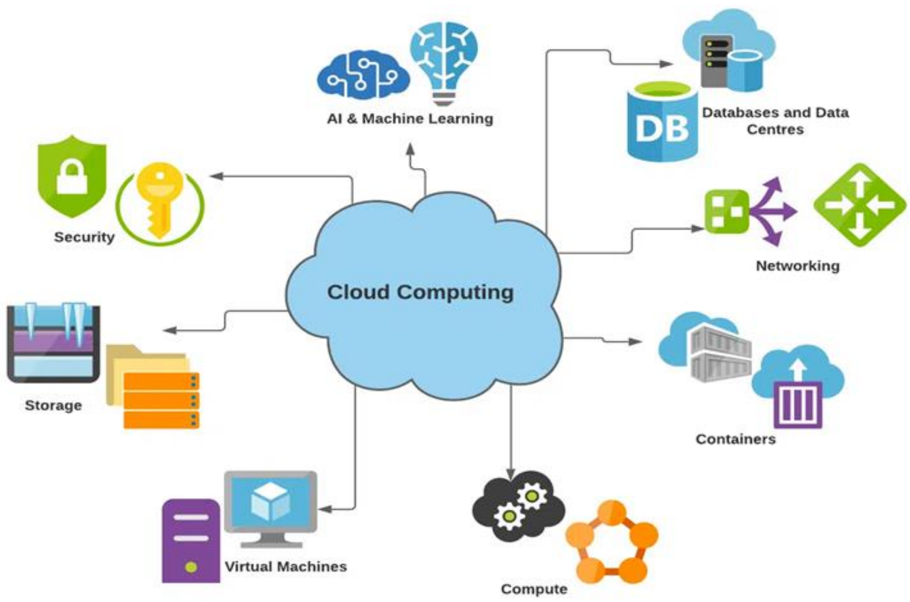

Figure 1: Cloud Computing.

However, Cloud computing comes in four primary flavors: multi-cloud, hybrid, private, and public clouds. Moreover, cloud computing services come in three primary varieties: Platforms as a Service (PaaS), Software as a Service (SaaS), and Infrastructure as a Service (IaaS) [16]. Selecting a cloud model or service is a special choice. No two clouds are same, nor are any two cloud services utilized to address the same issue. However, by recognizing the commonalities, you may better understand how each type of cloud computing and cloud service's limitations may affect your business's operations [17]. Overall, when cloud computing offers affordable, scalable, and manageable solutions that support quick growth and innovation, it has completely changed the way businesses run. Although cloud computing platforms offer flexible and on-demand processing and storage capabilities, they have revolutionized the way businesses work [18].

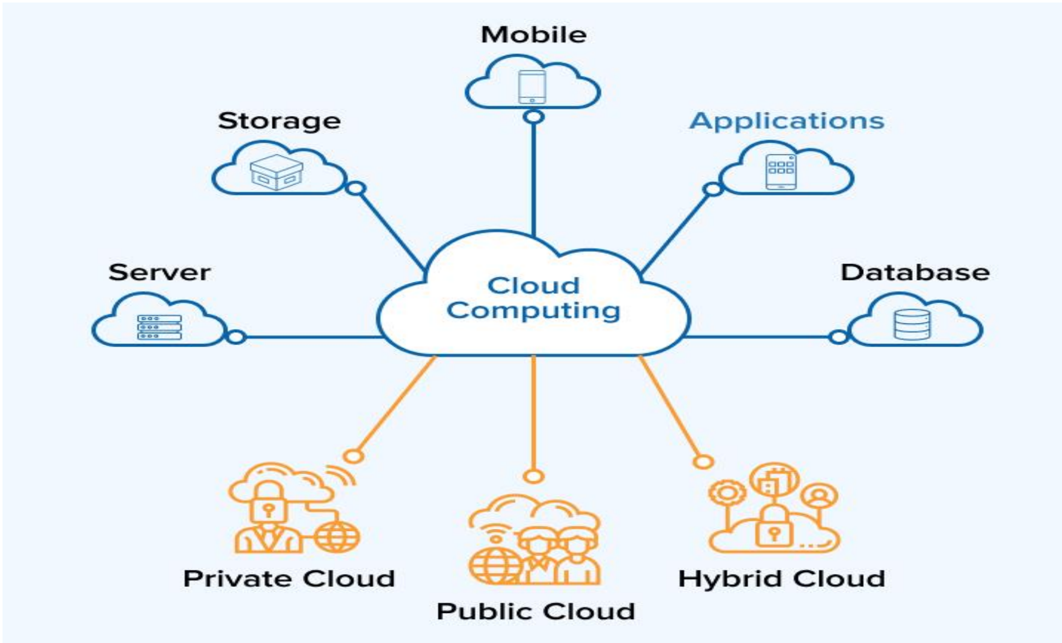

Figure 2: Types of Cloud Computing

B.2. Cloud Architecture

The term "cloud architecture" describes the layout and organization of a cloud computing environment, which includes how resources, programs, and services are split up among several cloud service providers. In order to ensure scalability, dependability, and security in a cloud computing environment, cloud architecture is essential. Realizing that cloud computing is essentially a simultaneous service is critical for comprehending and utilizing it successfully [19]. Valuable resources like data, information, and knowledge must be stored safely and protected from natural disasters, as well as flow to and from the user in an easy and secure manner.

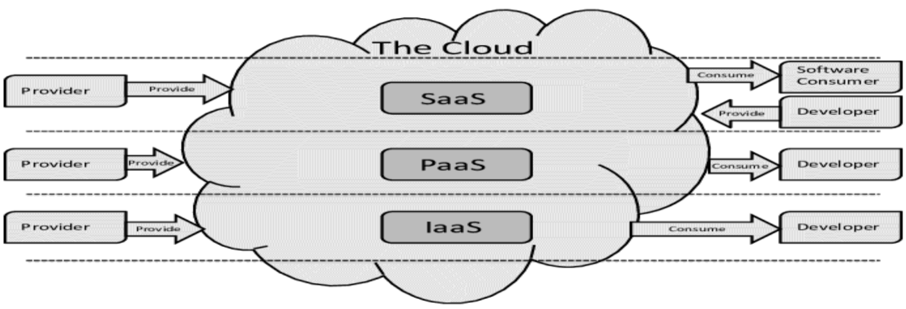

Figure 3: Cloud Computing Architecture

Large-scale computing tasks and a variety of IT operations, including storage, compute, database, and application services, can now be effectively completed with the help of cloud services. The architecture, which refers to the parts, subparts, and overall system structure of cloud computing, is a crucial component of the expertise [6]. There are numerous distinct cloud computing architectures and infrastructures that can be used to fully utilize the potential of cloud computing. Best practices and recommendations for creating and executing cloud-based application design are offered by these architectures [20]. Cloud architecture typically involves the following key components:

i. **Cloud Service Models:**
   - **Infrastructure as a Service (IaaS):** Offers virtual computers, storage, networking, and other virtualized computing services via the internet.
   - **Platform as a Service (PaaS):** Gives consumers a platform to develop, run, and maintain applications without worrying about infrastructure limitations.
   - **Software as a Service (SaaS):** Eliminates a requirement for users to set up, uphold, and regulate software applications domestically by delivering them across the internet.

ii. **Deployment Models:**
   - **Public Cloud:** The facilities are presented via the open internet to anyone who desires to use them.
   - **Private Cloud:** Additional oversight and customizing are available when services are delivered through a private network, usually inside an organization.
   - **Hybrid Cloud:** Combines elements of public and private clouds to allow apps and data to be shared among them.

iii. **Cloud Infrastructure Components:**
   - **Compute Resources:** Software can be processed and run using server-less computing, virtual machines, and containers.
   - **Storage:** Alternatives to scalability and permanent information keeping, such as file, block, and object storage.
   - **Networking:** The infrastructure to facilitate connectivity between different cloud services and elements.

iv. **Cloud Services:**
   - **Identity and Access Management (IAM):** Protects cloud resources from unauthorized access by controlling user identities and rights.
   - **Database Services:** Assistance with controlled databases that provide dependable and extensible storage of data.
   - **Security Services:** Services and instruments for guaranteeing infrastructure, data, and apps are secure.
   - **Monitoring and Logging:** Services to keep a tab on cloud resource activity, health, and performance.

v. **Orchestration and Management:**
   - **Automation:** Resources and services for decreasing staff involvement, improving productivity, and automation traditional processes.

- **Orchestration:** The administration and coordination of several cloud services to ensure smooth collaboration.

vi. **Scalability and Elasticity:**

- **Scalability:** The capacity of a system to increase resources in order to accommodate a growing workload.
- **Elasticity:** The capacity to adjust resources automatically in response to requirements.

vii. **Fault Tolerance and High Availability:**

- **Redundancy:** Important parts are duplicated to guarantee system availability in the event of an interruption.
- **Load Balancing:** Dividing up network traffic among a number of servers in order to prevent a single point of failure.

viii. **Data Management and Governance:**

- **Data Encryption:** Utilizing encryption to guarantee the integrity and security of data.
- **Data Governance:** Guidelines and procedures for data lifecycle management.

The architecture of clouds is flexible and always changing in response to technological breakthroughs. Businesses create their cloud architectures according to their own requirements, taking cost-effectiveness, effectiveness, safety, and conformance into account [11]. However, it is significant to remember that cloud-based apps currently lack a standard architecture or basic design guidelines. As was mentioned, the achievement of cloud computing based on the creation of a regulated and scalable cloud architecture. This architecture should be driven by the needs of the market, controlled by the supply and demand for cloud resources, and easily expandable to accommodate changes in service levels.

B.3. Multi-Cloud

Utilizing several cloud computing services from various providers to spread workloads across various environments is known as multi-clouding [21]. Businesses use the capabilities of various cloud platforms rather than depending on a single cloud service provider to suit their wide range of needs. Improved robustness, more flexibility, and cost optimization are just a few advantages of this approach [17]. Key aspects of multi-cloud include:

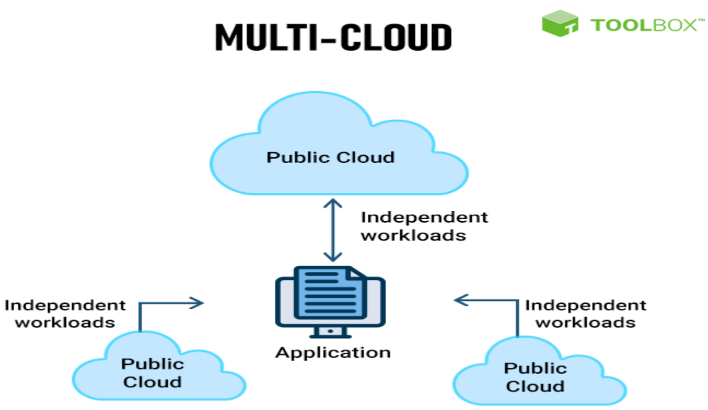

Figure 4: Multi-Cloud

i. Flexibility and Vendor Neutrality:

Depending on particular requirements, multi-cloud setups give users the freedom to select the finest services from several providers. By avoiding vendor lock-in, this vendor-neutral strategy helps enterprises avoid becoming too dependent on a single provider.

ii. Risk Mitigation and Resilience:

The distribution of workload among several cloud providers lessens the impact of possible outages or service interruptions, improving resilience. Workloads can be moved to another cloud provider if there are problems with one, reducing downtime and guaranteeing business continuity.

iii. Optimization of Costs:

Using multi-cloud solutions, businesses can maximize expenses by comparing and choosing the best-value services from several suppliers. It makes it possible for businesses to take advantage of discounts and special offers from various cloud service providers, thus cutting costs overall.

iv. Geographic Reach and Compliance:

Due to multi-cloud setups, enterprises can distribute resources across many geographical locations, resolving issues with data residency and local law compliance. This is especially crucial for multinational companies that operate in several nations.

v. Best-of-Breed Solutions:

Various cloud service supplier are better at different things, such storage capacity, processing power, or specialized services. By using a multi-cloud strategy, businesses may select the best-of-breed solutions for every unique need, creating an infrastructure that is more specialized and efficient.

vi. Innovation and Future-Proofing:

Adopting an approach that utilizes multiple clouds puts businesses in a position to benefit from many providers' advancements. Additionally, it ensures that their infrastructure is future-proof and that they can quickly incorporate new services and technologies as they become available in the quickly changing cloud environment.

vii. Management and Orchestration:

Resilient orchestration and management solutions are necessary for multi-cloud environments to be managed effectively. Platforms for cloud management assist businesses in automating procedures across several cloud providers, streamlining operations, and keeping an eye on performance.

viii. Security Considerations:

A key component of any cloud strategy is security. To secure the safety of their data and apps, organizations using a multi-cloud strategy need to put strong security measures in place, such as identity and access management, encryption, and compliance controls. Despite the many advantages of multi-cloud computing, enterprises must properly plan and manage their multi-cloud setups in order to optimize benefits and minimize risks. This covers data interoperability, uniform security guidelines, and efficient administration and monitoring procedures [22].

B.4. Architecture of Multi Cloud

Multiple cloud computing services from various providers are used in multi-cloud architecture. By avoiding dependency on a single cloud provider, this strategy hopes to give businesses more flexibility, redundancy, and resource optimization [23]. The hybrid cloud and federated cloud are two important architectural approaches within the multi-cloud paradigm that are frequently addressed [19].

a. Hybrid Cloud Architecture:

Within the premises infrastructure and resources from one or more public cloud providers are combined in a hybrid cloud architecture. It establishes an integrated environment that enables smooth data and application sharing between on-premises and cloud settings [15].

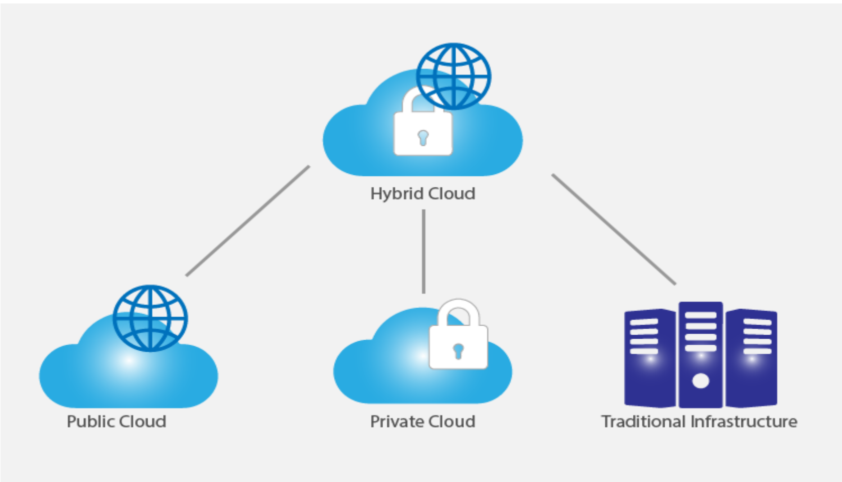

Figure 5: Hybrid Cloud Architecture

i. On-Premises Infrastructure:

Traditionally, businesses have owned and operated their own data centers with this kind of proprietary infrastructure.

ii. Public Cloud Infrastructure:

Makes use of resources from AWS, Azure, or Google Cloud Platform, among other public cloud services.

iii. Connectivity:

Between on-premises and cloud settings, fast and secure connections (such as VPN or specialized network links) are created.

iv. Orchestration and Management:

Software instruments and platforms that make it possible to manage resources consistently between public cloud and on-premises environments.

v. Data Integration:

Services and tools to enable smooth data transfer and integration across cloud-based and on-premises systems.

vi. Security and Compliance:

Ensuring data protection and regulatory compliance in hybrid settings requires strong security protocols and compliance frameworks.

b. Federated Cloud Architecture:

Federated cloud architecture uses a number of linked cloud service suppliers to provide an integrated, cooperative infrastructure. Providing a uniform view and access to resources across many clouds is the aim [24].

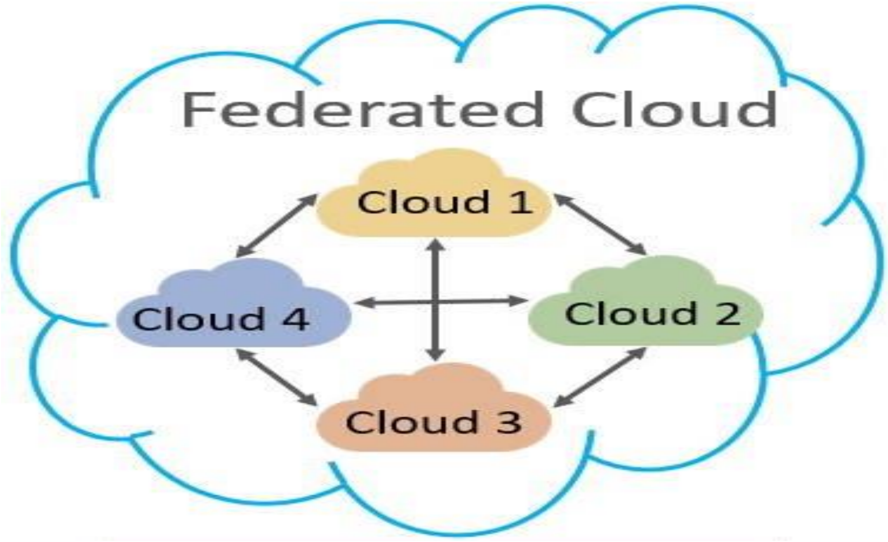

Figure 6: Federated Cloud Architecture

i. Multiple Cloud Providers:

Requires working with many cloud providers, each of which has unique resources and services to provide.

ii. Federation Middleware:

Software elements known as middleware provide collaboration of resources, authorization, and interaction among various cloud environments.

iii. Global Resource Directory:

A registry or directory offering a consolidated perspective of resources accessible throughout federated clouds.

iv. Identity and Access Management:

Unified identification and access control solutions to provide safe and easy resource access among federated clouds.

v. Data Interoperability:

Expectations and protocols that make it possible for data from various cloud providers to work together. In summary, organizations may fulfill dynamic business requirements with the flexibility and scalability offered by both hybrid and federated cloud infrastructures. A number of criteria, including data sensitivity, regulatory compliance, and particular company objectives, influence which of these models is best [25].

C. Literature Review

Authors in the study [26] are bringing to light different SLA and legal-based concerns in the federated hybrid and multi-cloud ecosystem that could cause cloud users to experience SLA breaches, operational inefficiency, lock-in of vendors, and security risks.. The paper categorizes the issues into different sections, federated cloud strategy, SLA problems, SLA metrics, SLA standardization, hybrid multi-cloud architecture, SLA troubles and SLA in the federated environments. Involves discussing numerous SLA and legal-based matters in the context of a federated hybrid and multi-cloud environments, as well as providing a use-case example to illustrate these issues. The paper categorizes its content into different sections, each focusing on specific aspects of SLA and legal challenges in cloud computing, The architecture types discussed in the study include public, private, hybrid, community, federated, intercloud, and multi-cloud models. The paper also highlights the need for implementing rules and policies for the success of cloud federations.

And the Authors in [27] putting forth a fault-tolerant design to facilitate system integration and offer a stable cloud environment for erratic temporary resources, proposing a prediction technique to compute failure probability and support FT definitions taking into account the current resource availability scenario, and building a platform-independent structure using a checkpointing execution strategy and FT criteria to ensure application execution. The study discusses two types of architectures for sustainable coverage and land use change: an agent-based emulator and a multi-cloud scenario-based framework.

While, the authors in [28] workload shifting is a suggested method for allocating workloads to various data centers; its goal is to reduce overall carbon emissions while maintaining average response times; it takes into account geographically dispersed data centers with varying carbon intensities and renewable energy availability; it also incorporates distributed data center design, resource management, and workload improvement. Cloud data centers confront difficulties brought on by excessive energy use and carbon emissions, improving resource utilization is a promising approach, geographically distributed data centers can enhance the availability of the whole system and provide more options for allocating requests.

The authors in [29] suggest a method that enables a Home Cloud to store its files in a Multi-Cloud Storage (MCS) system, ensuring data security and availability via obfuscation techniques. It introduces an abstraction layer on several heterogeneous cloud storage providers. Also, is tangible and simple to use in light of current Cloud storage providers. Test and validate a Multi-Cloud storage system composed of major Cloud Storage providers, extend the concept of Multi-Cloud storage system, and focus on optimizing data storage and retrieval while ensuring data availability and confidentiality, through clustered file systems, parallel file systems, highly fault-tolerant file systems like HDFS, and Cloud storage services with their common functionalities. The idea of a multi-cloud storage system is being extended from regular people to cloud operators, and evaluating the system will yield configuration guidelines.

In [30] the authors suggested to cloud computing faces challenges in providing shared virtualized resources, but various proposed approaches and scheduling algorithms have shown significant roles in utilizing these resources effectively. -Virtualization techniques have a significant impact on enhancing network performance, reducing costs, balancing load, conserving energy, and actively allocating resources to satisfy clients' requirements. Proposal of Random Algorithm for effective resource allocation by using of CloudSim simulator for evaluating the proposed method, and proposal of DSJF and DFCFS energy-saving resource allocation algorithms, and proposal of LCGA algorithm for effective task scheduling strategy, and "Skewness" approach used to compute resource usage on the server within Infrastructure as a Service (IaaS), Platform as a Service (PaaS), Software as a Service (SaaS). Contribute to review of recent methods for source provision in cloud computing, and highlighting the importance of requests execution time and VM availability in resource allocation approaches.

However, authors in [31] involves discussing the paper of single cloud services and multi-cloud computing environments, proposing effective resource sharing among cloud services, exploring the potential of hybrid cloud, and highlighting the need to develop a framework for secure resource sharing in a multi-cloud environment, within a Software as a Service (SAAS), Platform as a Service (PAAS), Infrastructure as a Service (IAAS), Public Cloud, Hybrid Cloud, Federated Clouds, and Multi-cloud architectures. They contribute to proposing a study of single cloud services and multi-cloud computing environments, addressing the challenges and benefits of multi-cloud computing, and emphasizing the need for a framework to address the shortcomings of existing systems and design secure resource sharing in the multi-cloud environment.

Furthermore, in the study [32] discussions on the working models and infrastructure mechanisms of cloud computing, the importance of proper resource scheduling, the role of virtualization, multi-cloud exchanges for optimizing connectivity, service level agreements, components of cloud computing frameworks and infrastructure, advancements in data center and cloud architectures, and the evolving nature of Hybrid IT through public, private, and hybrid architectures. its exploration and advocacy for the advantages and potential of multi-cloud exchanges and hybrid IT in enhancing the efficiency, security, and cost-effectiveness of IT operations in the digital business landscape.

While, in article [33] in especially in federated and multi-cloud systems, the authors describe the continuing research efforts in autonomous and optimal cloud service provider selection. Additionally, it offers a cutting-edge method for choosing cloud service providers in a federated, decentralized setting, aiming to enhance performance, reduce hosting costs, and improve profit. The approach used in the paper is "Automatic and Optimal Cloud Service Provider Selection" and discusses the use of matchmaking algorithms for CSPs selection. Also discussed in decentralized federated environments, dynamic resource allocation across multiple Clouds, ''light'' Federations with data exchange systems, and hierarchical management of SLA-based service selection. These architecture types aim to enhance overall performance, reduce hosting costs, improve profit, and select appropriate services based on SLAs. Aims to active involvement in national and European projects associated to cloud computing and cloud federation, besides significant research contributions in the areas of cloud and edge computing, IoT, network virtualization, smart detecting situations, crowdsensing, and the application of blockchains and smart agreements to IoT/edge infrastructure and services.

The authors in [34] doing a comprehensive analysis of several cloud computing infrastructure and model of service variations, a comparative study based on various factors, and the importance of choosing the most suitable cloud model for specific needs. However, discussed the study about IaaS, FaaS, SaaS, Private Cloud, Public Cloud, Hybrid Cloud, Community Cloud, Virtual Private Cloud, Inter-Cloud (Federated Clouds, Multi-clouds). Experts talked about how crucial it is for businesses to comprehend the distinctions between the many kinds of cloud computing. A table-based comparison of all cloud computing deployment options is also included in the report, which covers a number of different topics like supported platforms, languages, storage capacity, services, and items.

Study in [35] the authors anticipated scheme leads to lower system latency compared to existing schemes. The paper is the first to consider three-layer Het-MEC networks with multiple independent CCs, MEC servers, and Eds, the study evaluates the inspiration of the numbers of CCs, MEC servers, and EDs on system expectancy. In order to deploy several apps distributedly on different independent cloud centers (CCs), each of which maps an application to a computing workload, they used a three-layer dispersed heterogeneous MEC (Het-MEC) network. The quantity of computing and transmission resources required for each job varies, as do the resources owned by each device. However, aimed to provide a new method for thinking about three-layer Het-MEC networks with numerous independent CCs, MEC servers, and EDs. They also introduced a joint task offloading and resource allocation algorithm (MARL-JTORA) based on reinforcement learning to minimize system latency in a distributed way. Finally, they built a pipeline-based data flow processing diagram to show the task latency and assessed how many CCs, MEC servers, and EDs have an impact on the system latency.

Also, in [36] authors suggested the exploration of hybridization possibilities of cloud computing, data mining, and big online data, the strategic value of big data for industrial upgrading and growth, the application of big data mining methods in cloud systems, and the use of big data analysis and IoT for studying and predicting COVID-19. However, they discuss theoretical and explorative approaches in data mining, and address the weaknesses and shortcomings in the hybridization of data mining. Also, propose a decentralized and online big data mining model within Command Information System architecture based on big data analysis, Client-server design architecture for data and data chunk adaptation, Hadoop architecture for big data and cloud platforms, Cloud computing clusters architecture for big data research. Therefore, to configurable computing resources shared pool for easy service provision, slight supervision effort or communication with service providers required, and wild and on-demand network access provided.

Authors in the study [37] imply that by eliminating duplicate data and preserving memory, the suggested optimized deduplication technique is advantageous for harvesting cloud storage. Therefore, The implementation of Federation Agent to centrally manage all transactions in a single federation table, the use of bloom filters to verify an element's membership in a federated cloud environment, and the suggestion of an optimal data duplication strategy utilizing file level deduplication technique. The study also suggests the potential for future research on wedge level deduplication practises in federated cloud situation, with Federated cloud architecture includes components such as Cloud Coordinator, Cloud Broker, and Concentrator, as well as the concept of Federated Cloud Identity management. It also involves the classification of cloud computing into IaaS, PaaS, and SaaS. The contributions of the paper include proposing an enhanced deduplication approach for federated cloud environment and introducing the concept of a central management mediator, referred to as the Federation Agent, to improve data duplication strategy. Additionally, the paper highlights the potential for future research on wedge level deduplication practises in the federated cloud environment.

The Author in [38] proposes a fault-tolerant cost-efficient workflow scheduling algorithm (FCWS) to address the challenges of multi-cloud systems, demonstrating its superiority in terms of cost and reliability compared to existing algorithms. It attained approaches include building a fault-tolerant workflow scheduling framework, analyzing task execution reliability and hazard rate using Weibull distribution, integrating different multicloud providers' billing mechanisms, defining a cost-efficient bottom level for DAG tasks, proposing a fault-tolerant cost-efficient workflow scheduling algorithm (FCWS), describing the time complexity of scheduling algorithms for applications with DAG model, and conducting extensive simulations to evaluate the performance of the proposed algorithm, within fault-tolerant, cost-efficient, parallel scientific applications scheduling architecture on multi-cloud systems. The contributions of the study include the development of a multi-cloud systems fault-tolerant workflow scheduling framework and the proposal of the FCWS algorithm, which aims to minimize application execution cost and time while guaranteeing reliability. The paper demonstrates that the FCWS algorithm outperforms existing algorithms in terms of cost and reliability through extensive simulations based on real-world scientific applications.

Also, in [39] the authors used a hybrid approach with three segments: Byzantine protocol for security breaches, DepSky architecture for reliability and secrecy of data, and Shamir undisclosed sharing technique for trustworthiness and disclosure of data storage. The paper also discusses the benefits of a multi-cloud hosting environment over a single cloud hosting environment, as well as various models and frameworks proposed by other researchers to improve information security in multi-cloud environments. Also, the study works in three architectures are: Byzantine protocol for tolerant security breaches to server failures in the cloud, DepSky architecture for boosting consistency and confidentiality of data maintained in the cloud employing encoding and decoding techniques, and Shamir secret sharing procedure to improve trustiness and privacy of data storage without impacting performance. However, to attained the design and implementation of a hybrid approach for improved security and privacy of cloud data in a multi-cloud hosting environment, comparison of the hybrid method with other protocols for diverse user facility desires, and evaluation of the presentation of the hybrid method in standings of encryption/decryption time and storage utilization.

While in [40], the researchers discussing the concept, challenges, requirements, and future directions for the multi-cloud environment, surveying prevailing methods and resolutions provided by diverse multi-cloud architectures, and providing an investigative assessment of numerous multi-cloud architectures and a proportional analysis of their pros and cons. And from the Federated Cloud, Multi-provider hosting, Open Contrail project architecture, mOSAIC model, User-centric idea of cloud with virtual private cloud (VPC), Intangible sight of uncoupling SaaS, PaaS, and IaaS clouds. While to providing a critical analysis of various architectures discussed in the paper, and indicating that, in the authors' opinion, the SUPERCLOUD project model is the best multi-cloud architecture approach currently in use.

While, in [41] authors are suggested a dominance of cloud computing as a technology, the use of nature-inspired algorithms for solving global engineering problems and specifically addressing the challenge of job scheduling in cloud computing, and the need for more research and optimized solutions in the field of task scheduling. Therefore, Utilizing multiple tenants, public, private, hybrid, infrastructure-as-a-service (IaaS), platform-as-a-service (PaaS), infrastructure as a service (IaaS), incorporated variant of the HHO algorithm with simulated annealing (HHOSA), and Discrete Symbiotic Organism Search (DSOS) algorithm for cloud scheduling tasks, they employed nature-inspired algorithms for scheduling optimization in cloud computing. Also, It helps with a summary of nature-inspired algorithms and how they are used in cloud computing, an analysis of the literature on how to use nature-inspired algorithms to optimize scheduling in cloud computing, and a discussion of the need for more study and better solutions in the area of task scheduling in cloud computing. The paper also emphasizes challenges and open-ended issues in implementing nature-inspired algorithms to solve real-world problems.

Authors in the study [42] proposed a region-based fuzzy possibilistic C-means clustering, multi-objective density-based spatial clustering, k-means algorithm, entropy-based monotonic scheduling algorithm, Bayes classifier algorithm, ant colony optimization (ACO), particle swarm optimization (PSO), reinforcement learning method, and backpropagation (BP) neural network. These methods are focused on improving resource allocation, load balancing, task scheduling, and VM allocation in federated cloud environments. And attained within users, schedulers, brokers, and the federated cloud itself. The federated cloud consists of data centers (DC) clustering and virtual machines (VM) clustering, with algorithms used for clustering and dynamic clustering based on varying capacity. Multiple brokers are involved to avoid single point failure problems. However, the study contributes a focus on clustering and task scheduling in federated clouds and the introduction of an entropy-based monotonic scheduling algorithm.

Therefore, authors in [43] proposed the classification of cloud federation formation protocols into reactive and proactive protocols, the proposal of three distinct mechanisms for cloud federation construction, and the comparison of the proposed SPHCFF with an existing mechanism CFFM in two scenarios depend on overload rates. Also, suggested a reactive and proactive protocols of Horizontal Cloud Federation Formation (HCFF), three protocols of cloud federation formation depend on supportive tournaments, and introduction of the notion of "Overlapping Federations" with the OPHCFF protocol, development of a new system depend on Inter-Cloud architecture, and comparison of SPHCFF with Cloud Federation Formation Mechanism (CFFM) in simulation. Therefore, they obtained a proposal of three protocols of cloud federation formation based on cooperative games, the ambition to improve the proposed protocol by considering SLA requirements, safety and confidence measures, and further expenditures such as vigor ingesting and VM relocation, and the intention to expand the proposed architecture to address the problematic of interoperability of IaaS cloud earners.

Researchers in [44], anticipated the machine learning approaches, including reinforcement learning (RL), deep learning (DL), and multiagent deep reinforcement learning (DRL), are used for solving unburdening difficulties in energetic federated systems by means of huge volumes of unidentified material. These approaches have advantages over traditional optimization methods due to their ability to quickly solve offloading problems and learn directly from the environment. That usage a cloud, edge, and fog computing systems, as well as centralized, distributed, horizontal, vertical, and hybrid federations. Researchers achieved to discussing the categorization of federation across cloud, edge, and fog systems, a comparative assessment of offloading based on conventional optimizing and machine learning methodologies, and dealing with significant research difficulties related with job overloading.

However, authors in the article [45] discusses the importance of monitoring in cloud computing, presents an architecture for resource monitoring in federated cloud infrastructures, and provides an overview of various existing architectures and tools for cloud federation and multi-cloud situations. Also, deploying a controling architecture in a real-time OpenStack-based FEDerated GENomic (FEDGEN) cloud testbed, and briefly discussing the MonPaaS monitoring tool. Also, FEDARGOS-V1 uses Nagios for tracking host statuses and service statuses, it supports both pull and push interactions for resource monitoring, in a controling architecture for federated cloud computing substructures. Contributes to enhanced monitoring architecture for federated cloud infrastructures, covers the present Distributed Architecture for reserve administration and monitoring in clouds (DAR-GOS), stretchy and strong monitoring resolution depend on publish-subscribe pattern, minimally-invasive processing and communication practices, and focuses on processing asynchronous event notifications at the alarm engine level.

Finaly, the authors in [46] presented of OUR-ACS, a multi-pronged strategy that takes into account both initial virtual machine placement and VM consolidation techniques, with the goal of minimizing data centers' energy usage, carbon output, and overall expenses in a federated setting. Using real-world datasets and the CloudSim Plus simulator toolbox, the suggested algorithm's effectiveness is assessed. Compared to competing algorithms, the suggested algorithm may be able to lower cloud data centers' overall energy usage, carbon emissions, and associated costs, according to the simulation results. Also, they attained a system architecture designed to support a federated situation where cloud earners share their infrastructure freely. It includes cloud brokers, cloud information services, cloud coordinators, and cloud users. The architecture supports a peer-to-peer architecture with the cooperation of cloud coordinators for providing a federated environment. However, OUR-ACS, a multiple-purpose technique, has been suggested in order to reduce the utilization of energy, carbon emissions, and overall expenses of data centers in a federated circumstance. The algorithm that is suggested takes into account either initial VM placement and VM consolidation methods, and it is shown to be compatible via both methods in a federated circumstance., and the proposed algorithm reduces energy consumption, carbon emission, and total costs by an average of 37.6%, 41%, and 25% respectively.

D. Discussion and Comparison

The literature reviews that have been looked at as a whole shed light on the many problems and solutions that exist in federated and multi-cloud ecosystems. These studies repeatedly highlight the complicated problems related to operational complexity, security concerns, and breaches of Service Level Agreements (SLAs). The obstacles can be systematically categorized into parts like measurements, standardization, SLA issues, and strategic considerations to provide a thorough picture of the environment. The variety of architectural approaches examined—public, private, hybrid, community, federated, and multi-cloud—highlights the intricacy of the state of cloud computing today. Furthermore, the focus on putting regulations and laws in place for cloud federations to succeed suggests that people are becoming more conscious of governance in these complex ecosystems.

A central issue in the literature is resource allocation, which covers topics like load balancing, virtualization strategies, energy efficiency, and efficient scheduling methods. Numerous strategies that have been put forth, from normalization-based hybrid service brokering to random algorithms, show a dedication to resource management optimization. In addition, the security and confidentiality talks clarify novel approaches to guarantee data availability, integrity, and privacy, like obfuscation, fault-tolerant architectures, and multi-cloud storage systems. The recurrent issue of workflow scheduling emphasizes the significance of effective job management in these intricate cloud systems. This theme is investigated through priority-based algorithms and multi-objective PSO-based techniques.

In the future, critical analysis points to areas where breakthroughs in dynamic SLA adaption, interoperability standards, security integration, and comprehensive resource management can be made. It becomes clear that user-centric viewpoints, environmental ideals, and ethical issues need more investigation. For a more thorough and sustainable evolution of federated and multi-cloud ecosystems, the studies recommend incorporating green computing principles, taking the regulatory landscape into account, and conducting extensive benchmarking against real-world situations. The reviewed literature essentially lays the groundwork for upcoming studies that will push the envelope in terms of knowledge and creativity in the ever-evolving field of cloud computing.

Table 1: The Main Characteristics of Literature Survey

Ref	Approach	Architecture	Contribution
[26]	SLA	public, private, hybrid, community, federated, intercloud, and multi-cloud models.	- comprehensive exploration of SLA and legal issues in federated hybrid and multi-cloud ecosystems - addressing these challenges and highlighting the potential impact on future cloud models and architectures.
[27]	- Multi-cloud fault-tolerant architecture. - Application-level fault tolerance. - User-transparent. - Machine learning model for multi-cloud environments	Multi-Cloud scenario-based, Agent-Based simulator	- Fault-tolerant architecture for transient servers in cloud computing. - Application-level fault tolerance. - User transparency in fault tolerance. - Machine learning model for multi-cloud environments.
[31]	Single cloud services. Multi-cloud computing.	- Multi-cloud. - Federated Clouds. - Public Cloud. - Private Cloud.	- Discusses features and problems of single cloud and multi-cloud computing. - Addresses data storage-related security issues and data availability. - Proposes a framework to overcome existing system shortcomings. - Highlights the need for secure resource sharing and interconnectivity in multi-cloud environments. - Mentions the high cost of IT infrastructure for small and medium-sized businesses. - Describes the aids of hybrid cloud in avoiding vendor lock-in.
[34]	Cloud computing service	IaaS, PaaS, SaaS, and	- Offers a thorough examination of

	models and deployment models	FaaS. Private Cloud, Public Cloud, Hybrid Cloud, Community Cloud, Virtual Private Cloud, Inter-Cloud (Federated Clouds, Multi-clouds)	deployment models and cloud computing services. - Compares different cloud deployment models based on various factors. - Helps users choose the right cloud for their services.
[35]	distributed scheme based on multi-agent reinforcement learning.	- Three-layer distributed multi-access edge computing (MEC) network. - Cloud centers (CCs)	- Investigating the multi-CC case in a three-layer Het-MEC network. - Designing a distributed mechanism for multiple clouds to determine task offloading and resource allocation. - Proposing a multi-agent reinforcement learning algorithm to minimize system latency.
[36]	- Hybridization possibilities of cloud computing, data mining, and big online data.	- Command information system based on big data analysis. - Client-server design for data and data chunk adaptation. - Hadoop for big data and cloud platforms. - Cloud computing clusters for big data research.	- Configurable computing resources shared pool for easy service provision. - Slight supervision effort or communication with service providers required. - Fast and on-demand network access provided.

Table 2: The Main Characteristics of Literature Survey and its Algorithms that used

Ref	Approach	Architecture	Algorithms Used	Contribution
[29]	Multi-Cloud Storage (MCS) system	- Clustered file systems. - Parallel file systems. - Scalable parallel file systems. - Resilient Cloud computing platforms	- BASE-64 - MD5	- Testing the Multi-Cloud Storage system to provide configuration guidelines. - Analyzing the performance of different Cloud storage providers in the system.
[30]	Skewness	Traditional architecture. Virtual architecture. (IaaS), (PaaS), (SaaS)	- DSJF (Shortest Job First) algorithm - DFCFS (Depth First Complete First Search)	- Review of recent methods for resource allocation in cloud computing. - Highlighting the importance of requests execution time and VM availability in resource allocation approaches.
[33]	- Optimization techniques.	decentralized federated environments. hierarchical management of SLA-based service	- Genetic - Matchmaking	- Cloud providers leverage virtualization technologies to abstract computer hardware resources. - Cloud Service Providers must respect SLAs and satisfy

		selection.		customer requests. - Cloud Federation enables medium-sized providers to share computing resources. - The interaction and cooperation among federated entities is being investigated.
[37]	- Optimized deduplication strategy. - Vital supervision mediator for the federation. - Deduplication technique.	Federated cloud IaaS, PaaS, and SaaS.	- Password authenticated key exchange protocol - AES algorithm - MD5 - Bloom Filters	- Through Federation Level Agreements (FLA), cloud federation enables providers to collaborate on facilities. - Researchers presented deduplication techniques to produce leftover packing from CSPs.
[38]	- RDLS algorithm. - Reliability aware scheduling algorithm. - Dynamic scheduling algorithm of DAG tasks. - Workflow scheduling algorithm (CWS).	Multi-cloud systems scheduling and methodical application model.	FCWS	- Proposed fault-tolerant cost-efficient workflow scheduling algorithm (FCWS) - Reduces application performance rate and period while confirming consistency
[39]	- Hybrid approach. - Byzantine protocol. - DepSky architecture. - Shamir secret sharing procedure.	- DepSky architecture. - Byzantine protocol. - Shamir secret sharing procedure	DepSky-AC	- Multi-cloud adoption is increasing and over 85% of enterprise IT organizations have migrated to multi-cloud environments. - Studied is the ability to secure data across single and multiple clouds.
[40]	- OPTIMIS cloud federation toolkit - CHARM multi-cloud model	- Multi-cloud - Federated cloud - FCM	CHARM	- EMA surveyed 260 enterprises, with 61% using two or more public cloud providers.
[41]	- Nature-inspired. - Discrete Symbiotic Organism Search (DSOS). - Cost-Effective Infrastructure as a Service (CEICES). - Integrated version of the HHO algorithm with simulated annealing (HHOSA).	- Cloud storage types: file, object, and block storage. - Multi-tenancy architecture: IaaS, PaaS, and SaaS models. - Trials of multi-tenancy: safety, power optimization, distribution of services, high availability.	- HHOSA - Nature-inspired - Negotiating	- To assign tasks to appropriate resources in cloud computing. - Reviews nature-inspired algorithms for optimizing scheduling in cloud computing. - Discusses and assesses the literature on scheduling optimization in cloud computing. - Suggests using the chaotic squirrel search algorithm (CSSA) to schedule multiple tasks in a cloud environment. - Highlights the importance of nature-inspired figuring and its procedures in improving cloud computing challenges.
[42]	- Data center	DC clustering and	- R-FPCM	- Handling resources and

	clustering - Virtual machine clustering. - Markov chain. - Intermediate broker. - Entropy-based monotonic scheduling	VM clustering.	- Markov chain - Fast 1 to N source plotting - Entropy-based monotonous scheduling	distribution in response to requests from arriving users. - Task scheduling and allocation of resources using meta-heuristic algorithm. - Minimized time in the designed federated cloud environment.
[43]	- Cooperative game approach used for cloud federation formation. - Three rules proposed: SPHCFF, PPHCFF, and OPHCFF	Hardware, Infrastructure, Platforms, and Application.	- Responsive rules of HCFF - Active rules of HCFF - SPHCFF - PPHCFF - OPHCFF - CFFM	proposes three rules of fog federation foundation. - Introduces the notion of "Overlapping Federations" with the OPHCFF protocol. - Develops a new system based on Inter-Cloud architecture. - Compares the proposed protocols with existing mechanisms. - Evaluates the performance of the proposed protocols through experiments.
[44]	- Traditional optimization-based offloading. - Machine learning-based offloading (supervised ML, DL, RL, DRL). - Reinforcement learning.	- Vertical federation: Federation at different levels resulting in 2-tier or 3-tier architecture. - Parallel federation: Federation among earners of the equivalent level. - Hybrid federation: Mixture of upright and straight federations.	- DDPG - LSTM	- Categorization of federalism among boundary, cloud, and foggy platforms. - Arrangement of probable divesting methods in a federated system. - Comparative study of outmoded optimization and machine learning methods for offloading. - Identification of key research challenges and future directions in offloading.
[46]	- Multiple Purposes algorithm entitled OUR-ACS. - Considers initial VM placement and VM consolidation methods. - Uses ClousSim Plus simulator toolkit with real-world datasets.	federated and non-federated environments. - Peer-to-peer construction through cloud arranger for federated atmosphere.	- ACS - Ant colony optimization (ACO). - Simulated-annealing-based bees algorithm (SBA)	- Suggests using OUR-ACS, a multiple-purpose technique, to reduce energy use, carbon emissions, and overall costs in a federated setting. - Takes into account strategies for both VM consolidation and initial VM placement. - Proposed algorithm reduces vigour ingesting, carbon emanation, and overall expenses by an average of 37.6%, 41%, and 25% respectively.

Table 3: The Main Characteristics of Literature Survey and its Tools that used

Ref	Approach	Architecture	Tools Used	Contribution

[28]	workload shifting	Distributed data center design, resource management, workload optimization	CloudSim	presented a system model that took into account the carbon footprint, energy from renewable sources, and data center energy use.
[32]	- Multi-cloud approach to hybrid IT.	public, private, and hybrid.	IT Management	- Subscription-based IT services with service level agreement (SLA). - Huge storage capacity up to 3000 GB. - Utility computing model for end users. - Multi-cloud strategy for reliability and cost control
[33]	- Optimization techniques.	decentralized federated environments. hierarchical management of SLA-based service selection.	OASIS CAMP, TOSCA	- Cloud providers leverage virtualization technologies to abstract computer hardware resources. - Cloud Service Providers must respect SLAs and satisfy customer requests. - Cloud Federation enables medium-sized providers to share computing resources. - The interaction and cooperation among federated entities is being investigated.
[38]	- RDLS algorithm. - Reliability aware scheduling algorithm. - Dynamic scheduling algorithm of DAG errands. - Workflow scheduling algorithm (CWS).	Multi-cloud systems scheduling and systematic request model.	EC2	- A fault-tolerant and cost-effective workflow algorithm for scheduling has been proposed (FCWS) - Reduces the duration and expense of executing an application and preserves consistency
[41]	- Nature-inspired. - Discrete Symbiotic Organism Search (DSOS). - Cost-Effective Infrastructure as a Service (CEICES). - Cohesive variety of the HHO procedure per simulated annealing (HHOSA).	- Cloud storage types: file, object, and block storage. - Multi-tenancy architecture: IaaS, PaaS, and SaaS models. - Encounters of multi-tenancy: protection, influence optimisation, circulation of facilities, high availability.	- CloudSim - DSOS - SOS - HHOSA	- To assign tasks to appropriate resources in cloud computation. - Reviews nature-inspired procedures for optimizing arrangement in cloud computation. - Discusses and assesses the literature on scheduling optimization in cloud computing. - Proposes a chaotic squirrel search algorithm (CSSA) for multi-task scheduling in the cloud aether. - Highlights the importance of nature-inspired computation and its procedures in improving fog computation challenges.

[43]	- Cooperative game approach used for cloud federation formation. - Three rules proposed: SPHCFF, PPHCFF, and OPHCFF	Hardware, Infrastructure, Platforms, and Application.	- CloudStack - Eucalyptus	proposes three rules of cloud federation foundation. - Introduces the notion of "Overlapping Federations" with the OPHCFF protocol. - Develops a new system based on Inter-Cloud architecture. - Compares the proposed protocols with existing mechanisms. - Evaluates the performance of the proposed protocols through experiments.
[45]	- private or public federated cloud infrastructures. - installed in the FEDGEN fog prototype, an actual-time Ethereum prototype.	- FEDARGOS-V1 is a federation internet computing infrastructure surveillance paradigm.	- Nagios - MonPaaS - FEDARGOS-V1 - DARGOS	- Enhanced monitoring architecture for federated cloud infrastructures. - Expands upon the Integrated Architectural for Cloud Resources Administration and Supervision (DAR-GOS) currently in use. - Versatile and resilient observation method founded on the publish-subscribe methodology. - Minimally-invasive computing and methods for interaction. - Focuses on processing asynchronous event notifications at the alarm engine level
[46]	- Multiple purpose algorithm named OUR-ACS. - Considers initial VM assignment and VM association methods. - Uses ClousSim Plus simulator toolkit with real-world datasets.	federated and non-federated environments. - Peer-to-peer construction per fog arranger for federated situation.	- CloudSim - Toolkit	- Proposes a multiple purpose technique named OUR-ACS to curtail vigour ingesting, carbon emanation, and overall overheads in a federated situation. - Considers mutually primary VM assignment and VM association methods. - Proposed algorithm reduces vigour ingesting, carbon emanation, and overall expenses by an average of 37.6%, 41%, and 25% respectively.

E. Extracted Statistics

The charts presented in this article offer a comprehensive visual representation of the diverse landscape of approaches, architectures, algorithms, and tools employed in the land of Cloud Architectures for Distributed Multi-Cloud Computing, based on a combination of previous works. These visual aids serve as invaluable tools for understanding the complex interplay of methodologies utilized in the field, providing a brief overview of the evolving landscape. Through particular categorization and explanation, the charts describe the variety of architectural frameworks, algorithmic models, and technological tools applied across various instances of multi-cloud computing.

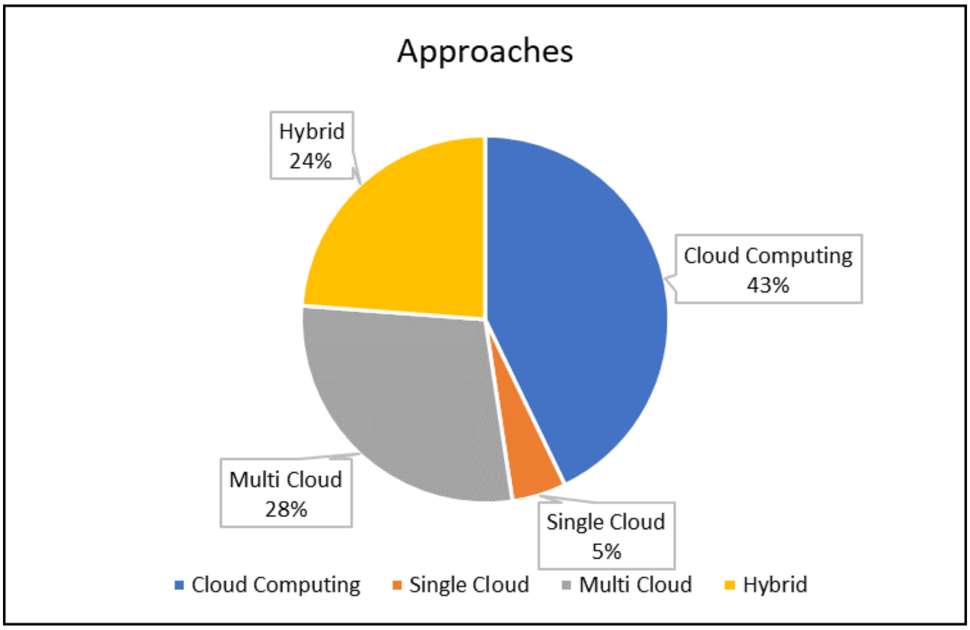

Figure 7: Statistic Chart of Approaches used by Previous Works

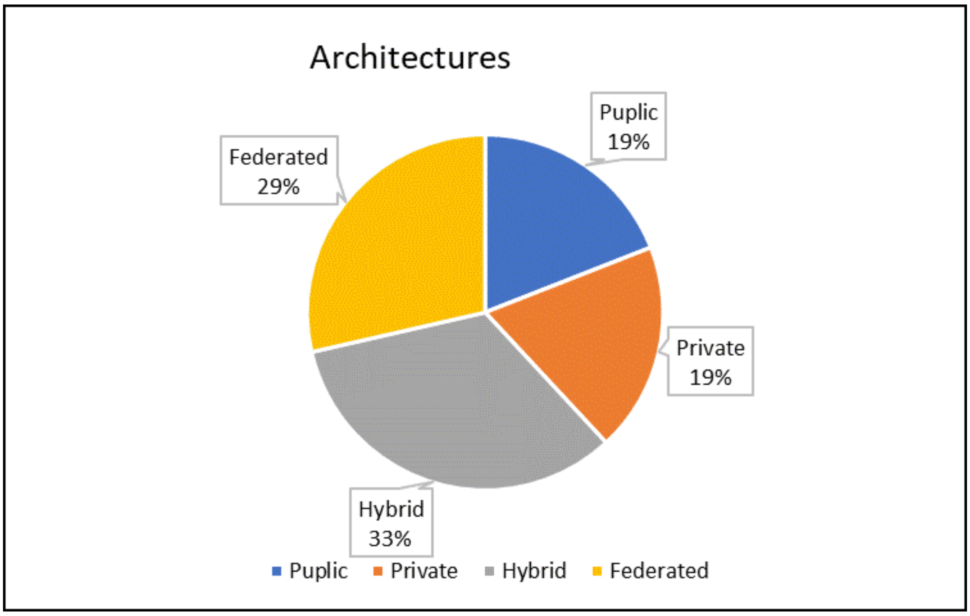

Figure 8: Statistic Chart of Architectures used by Previous Works

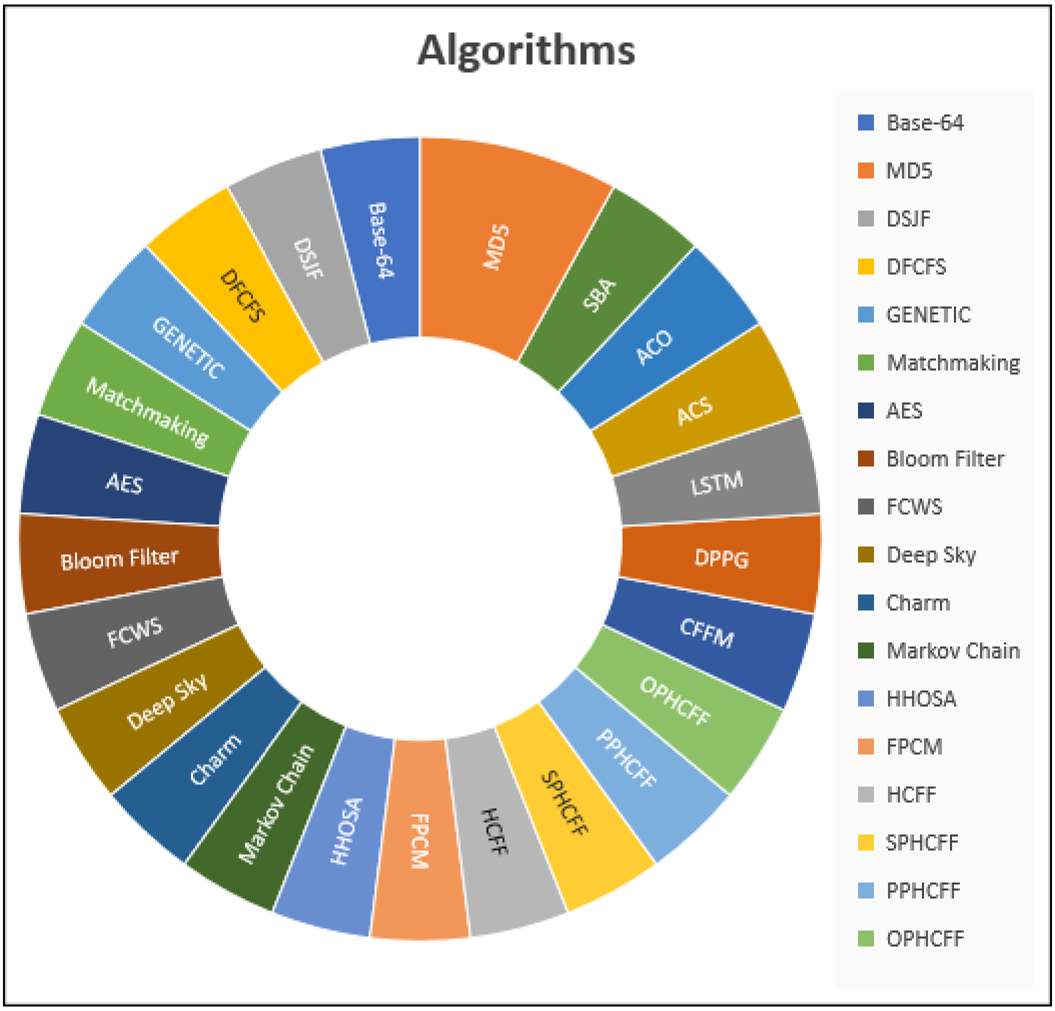

Figure 9: Statistic Chart of Algorithms used by Previous Works

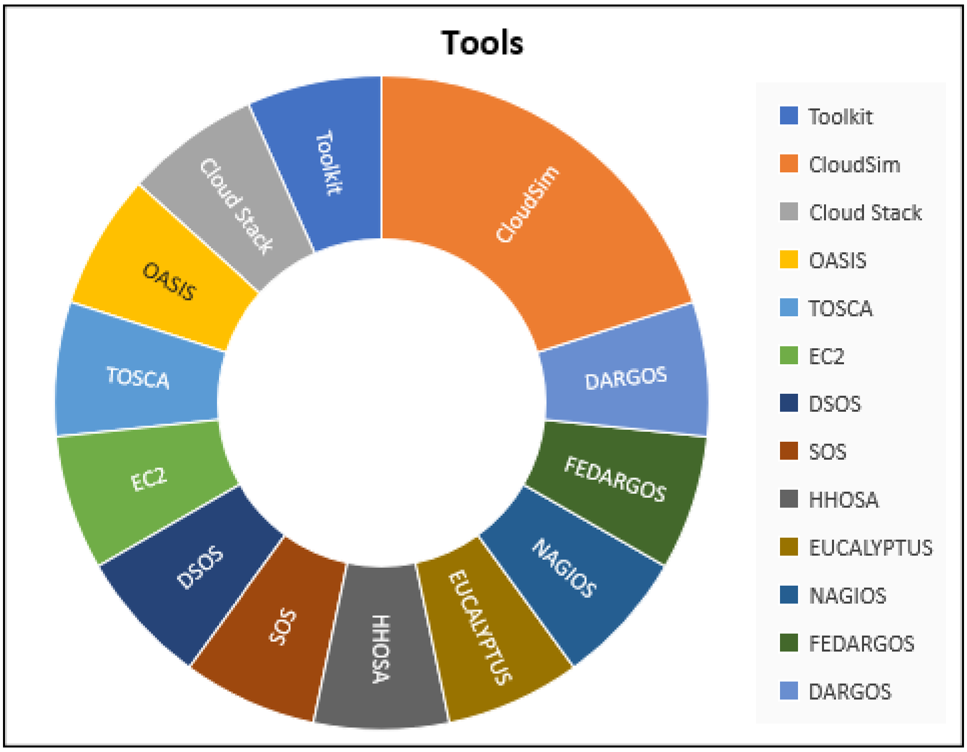

Figure 10: Statistic Chart of Tools used by Previous Works

F. Recommendations

A thorough review of the advances and difficulties in cloud computing, federated environments, and multi-cloud architectures is given by the extensive literature surveys. It is recommended that future study focus on a few important topics. Developing sustainable cloud practices to reduce carbon emissions, strengthening security and confidentiality in multi-cloud storage, optimizing resource allocation algorithms for different cloud services, advancing cloud federation formation protocols, utilizing machine learning for dynamic federated systems, investigating real-time monitoring tools for federated cloud infrastructures, designing multi-objective algorithms for cloud data center optimization, and further researching nature-inspired algorithms for cloud task scheduling are some of these. Other challenges include investigating interoperability issues in multi-cloud environments. These research directions aim to contribute to the ongoing evolution of cloud computing, fostering efficiency, security, and sustainability in the digital landscape.

Researchers are encouraged to handle the multidisciplinary issues in cloud computing in the future, taking efficiency, security, and environmental effects into account. Through exploring these domains, scholars can augment the ongoing refinement of cloud technologies, furnishing invaluable perspectives that mold the forthcoming terrain of cloud computing and federated environments.

G. Conclusion

In conclusion, a complex environment with creative solutions and difficulties is shown by a thorough review of a wide range of literature studies on federated and multi-cloud ecosystems. Together, the studies highlight the numerous problems pertaining to SLA breaches, operational complexity, vendor lock-in, and security, offering a structured perspective of the complicated cloud computing landscape. The investigation of several architecture types—public, private, hybrid, and multi-cloud models—highlights the necessity of strategic planning and governance for the development of effective cloud federations. A key subject is resource allocation, with a variety of strategies being put forth, from normalization-based hybrid service brokering to random algorithms, all of which emphasize a dedication to optimizing cloud resource management. Innovative techniques, like fault-tolerant designs and obfuscation, are used to address security and confidentiality concerns while maintaining data integrity and privacy. Another recurrent issue is workflow scheduling, which highlights how crucial effective task management is in the ever-changing cloud environment.

Future research priorities are highlighted via critical analysis, and these include the incorporation of security measures, the creation of interoperability standards, dynamic SLA adaptation, and comprehensive resource management. The ongoing development of federated and multi-cloud ecosystems depends critically on ethical issues, user-centric viewpoints, and sustainability principles. In order to shape a robust and sustainable future for cloud computing, it will be crucial to conduct extensive benchmarking against real-world scenarios, take into account the changing regulatory landscape, and integrate green computing ideas as the field develops. Essentially, the reviewed literature lays the groundwork for future investigations into fresh approaches and perspectives in the dynamic and always changing field of cloud computing.

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