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Blockchain-enabled Data Governance Framework for Enhancing Security and Efficiency in Multi-Cloud Environments through Ethereum, IPFS, and Cloud Infrastructure Integration

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Abstract: -In today's digital landscape, the exponential growth of big data demands secure and efficient processing, particularly in complex multi-cloud environments. This paper proposes an innovative blockchain-enabled data governance framework, revolutionizing data management, processing, and security across diverse cloud infrastructures. The framework integrates cutting-edge technologies, including the Ethereum blockchain, the InterPlanetary File System (IPFS) protocol, and cloud solutions like OpenStack and Red Hat OpenShift. At its core, the framework utilizes Ethereum's robust smart contracts and consensus mechanisms to establish a decentralized and secure data governance model. This ensures data integrity, transparency, and immutability, mitigating risks associated with centralized storage and processing. The IPFS protocol complements blockchain by offering efficient data sharding and retrieval mechanisms, enhancing data accessibility and fault tolerance in distributed cloud environments. Through comprehensive testing and analysis, the proposed framework's value is demonstrated. Performance metrics, including throughput, latency, CPU utilization, and memory utilization, were meticulously evaluated to assess system efficiency and scalability. Results indicate high performance, with Ethereum's Proof of Authority (PoA) consensus mechanism enabling efficient transaction throughput of up to 1000 transactions per second. Additionally, the IPFS protocol exhibits effective data retrieval capabilities, with an average latency of 15 milliseconds for data access operations.

Keywords: InterPlanetary File System (IPFS) protocol, Ethereum, OpenStack Private Cloud, Red Hat OpenShift, Proof of Authority (PoA) consensus mechanism.

I. INTRODUCTION

In the dynamic realm of data management, organizations grapple with securing data in multi-cloud environments [1]. Big data's rise intensifies challenges, demanding innovative solutions for modern, complex ecosystems [2]. This paper presents a blockchain-enabled data governance framework for decentralized big data processing [3]. Cloud computing, while transformative, introduces vulnerabilities like data breaches and vendor lock-in [4][5]. Multi-cloud setups add complexity to data governance and security [6]. The proposed framework utilizes blockchain's features for decentralized, secure data governance [7]. Blockchain ensures integrity, transparency, and accountability across distributed clouds [8]. Smart contracts, particularly Ethereum's PoA, facilitate secure data transactions, reducing risks [7]. Integrating IPFS enhances the framework by providing efficient data sharding and retrieval [9]. IPFS allows decentralized data storage, reducing reliance on centralized solutions and mitigating associated risks [10][11]. This blockchain-enabled framework tackles challenges posed by evolving data landscapes, offering secure and efficient solutions for multi-cloud environments [3]. The objectives are:

- Investigate the potential of blockchain technology; specifically Ethereum, to establish a decentralized data governance framework that ensures data integrity, transparency, and accountability.
- Explore the role of the IPFS protocol in complementing blockchain technology by offering efficient data sharding and retrieval mechanisms.

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- Evaluate the scalability, performance, and efficiency of the proposed blockchain-enabled data governance framework in real-world multi-cloud environments.
- Validate the effectiveness of the framework through testing and analysis, demonstrating its ability to address key challenges and deliver tangible benefits in terms of data security, integrity, and accessibility.

II. LITERATURE REVIEW

Current research explores the integration of blockchain into big data processing systems and multi-cloud architectures, aiming to establish trust and facilitate verifiable data transactions [12]. Interoperability challenges arise due to diverse protocols and standards across different blockchain platforms and cloud environments [13]. Privacy-preserving techniques, such as zero-knowledge proofs and homomorphic encryption, address data confidentiality concerns in decentralized settings [14]. These methods balance privacy and transparency, providing tamper-proof audit trails for tracking data provenance across multi-cloud platforms [15]. However, challenges persist, including scalability issues, high implementation costs, and complexities in ensuring compliance with data protection regulations in decentralized environments [16].

The integration of blockchain demands specialized expertise and consideration of factors like network consensus protocols and cryptographic techniques [17]. Despite introducing transparency and audibility, blockchain poses new security challenges that must be addressed for robust data governance frameworks. The literature acknowledges blockchain's potential to revolutionize data management in multi-cloud environments[20-22]. In the realm of cybersecurity, a novel security architecture called VBQ-Net is proposed to enhance intrusion detection and defence mechanisms against cyber threats in growing and technologically advanced IoT systems [18]. Another research contribution, the Attacker Identification using Region Splitting (AIRS) scheme, focuses on efficient region-based intrusion detection in Mobile Ad hoc Networks (MANETs) to counter jellyfish attacks, neighbour attacks, and location disclosure attacks. The scheme is compared with the existing Secure Routing Attacker Identification (SRAI) approach, demonstrating its response scheme's performance in various scenarios [19].

III. PROPOSED WORK

The proposed work aims to develop a comprehensive framework for decentralized and secure big data processing across multi-cloud environments, leveraging blockchain technology for enhanced data governance. This framework addresses the challenges of data integrity, security, and regulatory compliance in multi-cloud settings by integrating innovative technologies such as blockchain, IPFS protocol, and cloud infrastructure management solutions.

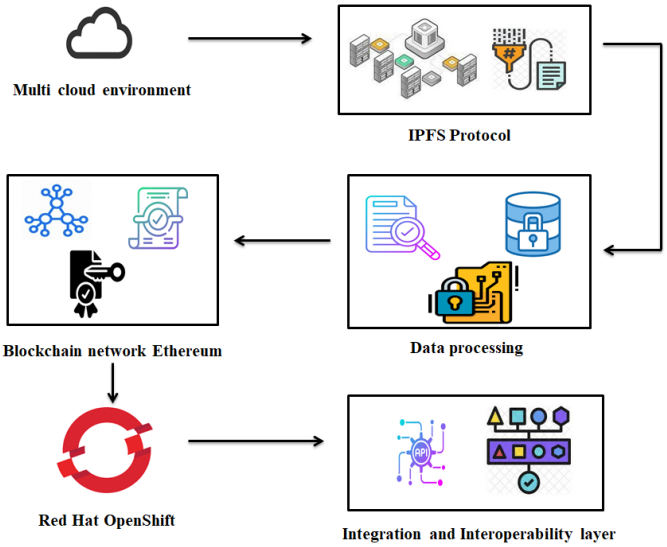

Figure.1 Data governance framework in Multi Cloud Environment

A. *InterPlanetary File System*

The workflow involving the IPFS protocol begins with the process of data sharding, where incoming data is fragmented into smaller, more manageable pieces. This sharding process is integral to the decentralized storage architecture facilitated by IPFS, as it enables data to be distributed across a network of IPFS nodes. Once the data is sharded, each fragment is assigned a unique cryptographic hash identifier, allowing for efficient retrieval

and verification of data integrity. These sharded data fragments are then distributed across the IPFS network, with each node responsible for storing a portion of the data. IPFS uses content-based addressing, where files are identified by their content rather than their location. This ensures that identical files will have the same hash, allowing for deduplication and efficient storage utilization. IPFS nodes automatically cache frequently accessed data, improving performance and reducing bandwidth usage for subsequent requests. This caching mechanism also facilitates content delivery, enabling faster access to popular or frequently requested content. As data is distributed across the IPFS network, redundancy and resilience are inherently built into the system. Multiple copies of each data fragment are stored across different nodes, ensuring fault tolerance and mitigating the risk of data loss or corruption.

When data needs to be accessed or retrieved from the IPFS network, clients can issue requests for specific data fragments using their corresponding cryptographic hash identifiers. These requests are routed through the IPFS network, with nodes collaborating to locate and retrieve the requested data fragments. Once the data fragments are retrieved, they are reassembled into their original form, allowing clients to access the complete dataset. This retrieval process leverages the decentralized nature of the IPFS network, enabling data to be retrieved quickly and efficiently from multiple distributed nodes. The IPFS protocol provides a robust and decentralized mechanism for storing, retrieving, and sharing data across a distributed network. By leveraging IPFS, the data governance framework ensures that data remains accessible, secure, and tamper-proof, even in the face of network disruptions or node failures.

B. Blockchain Network Ethereum

The Ethereum blockchain drives a decentralized data governance framework for multi-cloud environments, ensuring transparency and integrity. Transactions, including access controls and audits, undergo validation through the PoA consensus mechanism, maintaining the blockchain's integrity. Smart contracts enforce predefined rules, overseeing access controls, compliance, and audits. The blockchain ledger records all data governance transactions, creating an immutable audit trail for compliance monitoring. Continuous monitoring, analysis, and optimization enhance performance, security, and compliance. Stakeholder feedback refines data governance policies, ensuring adaptability to evolving challenges. The framework facilitates seamless data exchange and interoperability with external systems through API gateways. Authorized users interact with the Ethereum network to access data governance features, while compliance management tools monitor data access for regulatory adherence. This comprehensive yet concise approach enhances transparency, accountability, and resilience in managing data governance in complex multi-cloud environments.

C. Integration Layer

The integration and interoperability layer plays a crucial role in facilitating seamless communication and data exchange between various components within the blockchain-enabled data governance framework. Red Hat OpenShift, as a container application platform, provides a robust and scalable infrastructure for deploying and managing containerized applications, including those involved in data governance and big data processing. Within the integration and interoperability layer, Red Hat OpenShift serves as the foundation for orchestrating the deployment and operation of containerized services and applications. This includes components such as API gateways, event brokers, data pipelines, and identity providers, which are essential for integrating and coordinating the flow of data and operations across different systems and services. API gateways act as the entry point for external systems and services to access functionalities exposed by the data governance framework. Red Hat OpenShift facilitates the deployment and management of API gateways, ensuring secure and reliable communication between internal components and external entities.

Event brokers enable asynchronous communication and integration between services within the framework. Red Hat OpenShift provides support for event-driven architectures, allowing event brokers to efficiently distribute and process events generated by various components efficiently, enabling real-time data processing and analysis. Data pipelines orchestrate the flow of data within the framework, facilitating the ingestion, processing, and analysis of big data. Red Hat OpenShift supports the deployment of data pipeline components, ensuring scalability, fault tolerance, and performance optimization for data-intensive operations. Integration with identity providers is crucial for authentication and authorization within the data governance framework. Red Hat OpenShift enables seamless integration with identity providers, allowing users and applications to authenticate securely and access resources based on their roles and permissions. Red Hat OpenShift provides a flexible and scalable platform for deploying and managing containerized services and applications. By leveraging Red Hat OpenShift's capabilities, the data governance framework can seamlessly integrate with

external systems and services, enabling efficient data exchange, communication, and collaboration across multi-cloud environments.

D. Implementation

This work proposes a robust framework for decentralized, secure big data processing in multi-cloud environments. Integrating IPFS, Ethereum blockchain, OpenStack, and Red Hat OpenShift, the framework ensures scalability and redundancy across diverse cloud providers. The IPFS Protocol layer provides decentralized, secure storage through data sharding and hashing mechanisms, enhancing data resilience. Ethereum's blockchain layer serves as the backbone, maintaining a transparent, immutable ledger with the PoA consensus mechanism ensuring transaction integrity. The data governance layer enforces policies through smart contracts, covering access control, compliance, auditing, and encryption. The cloud infrastructure layer, comprising OpenStack and Red Hat OpenShift, offers underlying resources for efficient processing. The integration layer ensures seamless communication, with API gateways, identity providers, and event brokers facilitating data flow and analysis. This framework enhances data security, integrity, and efficiency in multi-cloud environments.

$$C = \sum_{i=1}^{N} C_i \tag{1}$$

Here C represents the cost of executing smart contracts on the blockchain, and C_i represents the cost associated with each individual smart contract operation.

$$R_{data} = 1 - (1 - P_{loss})^{N_{replica}} \tag{2}$$

R_{data} represents the overall resilience of the data stored in the IPFS network, P_{loss} represents the probability of data loss for a single data replica, $N_{replica}$ represents the number of replicas or redundant copies of the data stored in the IPFS network.

IV. RESULT

The experimental setup entails the deployment of a robust cloud infrastructure comprising OpenStack private cloud and Red Hat OpenShift clusters. OpenStack is configured to manage virtualized resources, while Red Hat OpenShift orchestrates containerized applications and services across the infrastructure. This provides the foundational layer for hosting and managing the components of the data governance framework. Next, the implementation involves deploying and configuring the IPFS protocol to establish decentralized and secure storage mechanisms for big data processing. Multiple IPFS nodes are deployed across the cloud infrastructure to ensure data redundancy and integrity. Configuration of data sharding and hashing mechanisms is essential to maintain data integrity and availability across the distributed network of IPFS nodes. Simultaneously, the Ethereum blockchain network is set up to serve as the backbone of the data governance framework. Ethereum nodes are deployed to establish a blockchain network, and the PoA consensus mechanism is configured to validate transactions and maintain the integrity of the blockchain ledger. Smart contracts are developed to define data governance rules and policies, including access control mechanisms, compliance management, auditing, and encryption, which are then deployed on the Ethereum network. In parallel, the integration and interoperability layer is configured to facilitate seamless communication and data exchange between the framework components.

This involves setting up API gateways to manage external access to framework functionalities and integrating identity providers for secure authentication and authorization. Event brokers are implemented to orchestrate data pipelines for real-time data processing and analysis, ensuring efficient data flow and analysis across the framework. The rigorous testing and evaluation are conducted to validate the performance, scalability, security, and compliance of the data governance framework. Comprehensive testing methodologies are employed to assess factors such as throughput, latency, resource utilization, and adherence to regulatory requirements.

Table.1 InterPlanetary File System in Multi Cloud Node

Node ID	Data stored (GB)	Data replicated	Data availability (%)	Storage utilization (%)
1	500	10	95	70
2	480	9	93	65

3	520	11	97	75
4	490	10	94	68
5	510	11	96	72

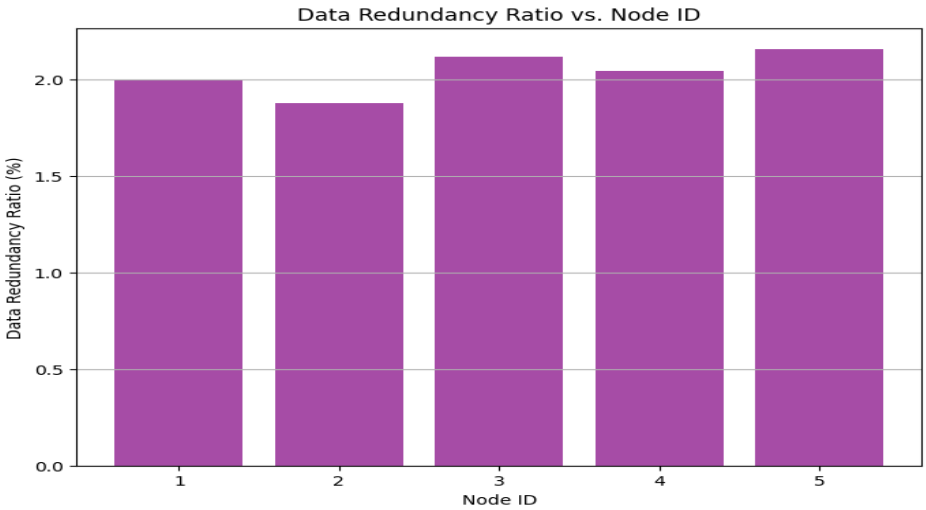

Figure 2 Data Redundancy Ratio in IPFS

The graph depicts the data redundancy ratio across various nodes within the system, offering valuable insights into the redundancy levels of the data storage infrastructure. Each bar in the graph represents a specific node, identified by its unique node ID, while the height of the bars indicates the corresponding data redundancy ratio measured as a percentage. It is observed that node 1 exhibits a data redundancy ratio of approximately 2.00%, while node 2 shows a slightly lower ratio of about 1.88%. Conversely, node 5 demonstrates the highest data redundancy ratio among the nodes, standing at approximately 2.16%. Nodes 3 and 4 fall in between, with ratios of approximately 2.12% and 2.04%, respectively. These numerical insights reveal varying levels of redundancy across the nodes, highlighting the proportion of replicated data in relation to the total amount of stored data. Higher Data Redundancy Ratios signify a greater redundancy level, indicating a more extensive replication of data to ensure fault tolerance and data reliability within the system.

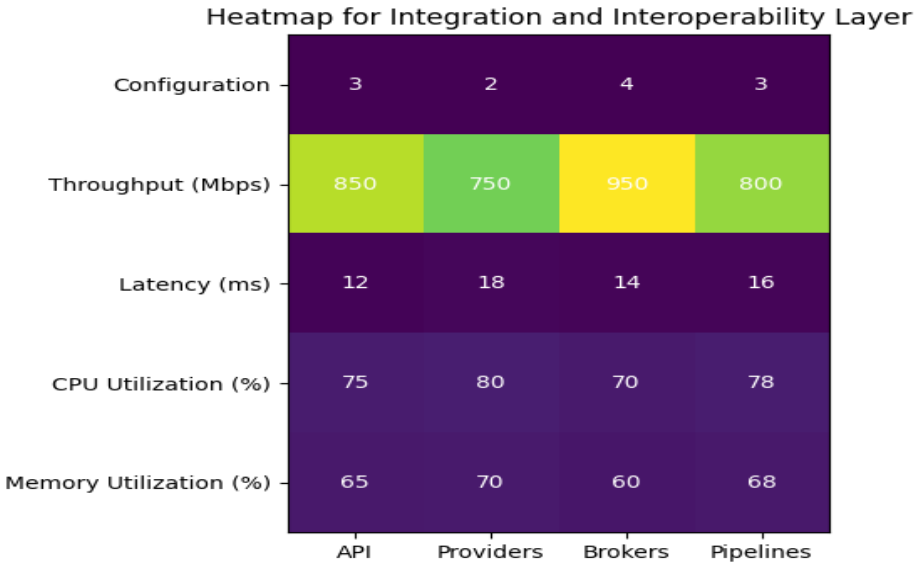

Figure.3 Metrics of Integration and Interoperability Layer

The provided heatmap illustrates various metrics and configurations within the integration and interoperability layer. The x-axis labels represent different components such as API gateways, identity providers, event brokers, and data pipelines. Event brokers exhibit the highest throughput with 950 Mbps, followed closely by API gateways and data pipelines. The latency measurements in milliseconds (ms), depicting the time taken for data transmission. Event brokers maintain the lowest latency at 14 ms, indicating efficient

data processing. A CPU utilization percentage represents the amount of processing power consumed by each component. Identity providers register the highest CPU utilization at 80%, suggesting intensive computational tasks. Memory utilization percentages reveal the memory usage of each component. API Gateways utilize memory resources most efficiently, with a utilization rate of 65%.

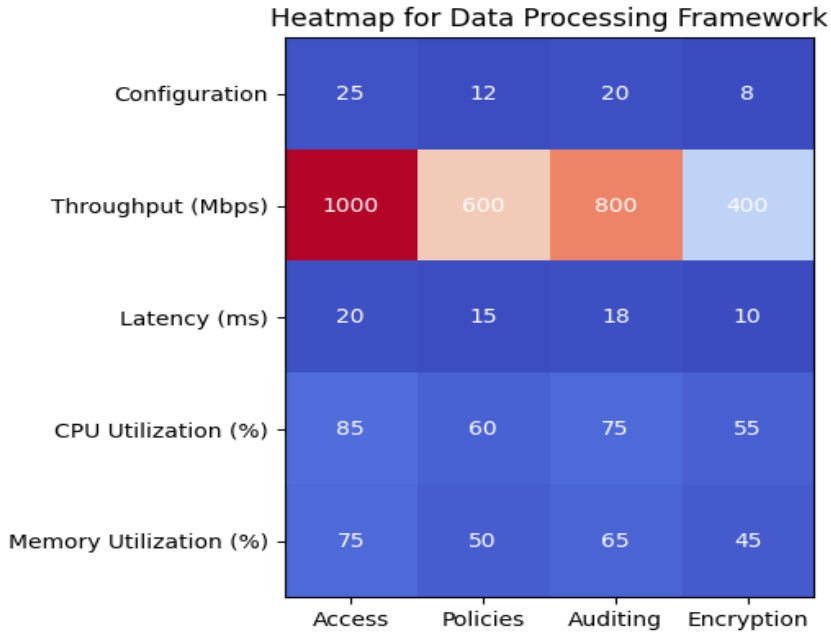

Figure.4 Metrics of Data Processing Framework

The provided heatmap visualizes key metrics and configurations within the data processing framework. The x-axis labels represent data access control, compliance policies, data auditing and data encryption. Notably, the system is configured with 25 data access control rules, 12 compliance policies, 20 data auditing rules, and 8 data encryption policies. Data access control exhibit the highest throughput at 1000 Mbps, followed by data auditing with 800 Mbps. Latency measurements in milliseconds (ms), reflects the time taken for data processing. Data encryption policies demonstrate the lowest latency at 10 ms, indicating efficient data encryption processes. CPU utilization percentages are analyzed to understand the proportion of processing power utilized by each component. Data access control exhibit the highest CPU utilization at 85%, indicating intensive computational tasks. Memory utilization percentages reveal the memory usage of each component. It is noteworthy that data access control also demonstrates the highest memory utilization at 75%, suggesting significant memory consumption within the framework.

Table.2 Performance Testing in Data Governance

Test run	Throughput (Mbps)	Latency (ms)	CPU utilization (%)	Memory utilization (%)	Storage utilization (%)
1	750	15	70	80	60
2	850	12	75	85	65
3	700	18	68	78	55
4	800	14	72	82	62
5	780	16	71	81	61

Throughout the testing, the system's throughput fluctuated between 700 and 850 Mbps. This variability in throughput indicates the system's ability to process data at different rates under varying conditions. Latency values ranged from 12 to 18 milliseconds (ms), reflect the system's responsiveness and efficiency in handling data transactions. CPU utilization, representing the percentage of the processing capacity, ranges from 68% to 85% across the test runs. These fluctuations in CPU utilization highlight the varying computational demands placed on the system during different testing scenarios. The variations in memory utilization underscore the dynamic nature of resource allocation within the system. The consistency in storage utilization suggests efficient management of storage resources within the system.

Figure 5 Efficiency Ratio of Performance Testing

The efficiency ratio graph offers insights into the relationship between system efficiency and resource utilization across various test runs. Each point on the graph corresponds to a specific test run, represented along the x-axis, while the y-axis portrays the efficiency ratio, a metric calculated by dividing throughput by CPU utilization for each test run. This ratio quantifies the system's efficiency in data transfer relative to the processing power consumed. In test run 1, the efficiency ratio is approximately 10.71 Mbps per percentage of CPU utilization. Test run 2 exhibits an efficiency ratio of around 11.33 Mbps per percentage of CPU utilization. Test run 3 records an efficiency ratio of about 10.29 Mbps per percentage of CPU utilization. Test run 4, the efficiency ratio is approximately 11.11 Mbps per percentage of CPU utilization and test run 5 demonstrates an efficiency ratio of roughly 10.99 Mbps per percentage of CPU utilization. These numerical insights underscore how effectively the system utilizes CPU resources to achieve data transfer goals across different test scenarios. Higher efficiency ratio values signify better utilization of processing power for data transfer tasks, reflecting improved system performance efficiency.

V. CONCLUSION

The utilization of blockchain, alongside technologies like IPFS and cloud infrastructure solutions, enhances data integrity, transparency, and accessibility, paving the way for efficient and scalable big data processing. Through the exploration of various technological components and their implications, several key insights have emerged. The utilization of blockchain, particularly Ethereum, offers robust data governance mechanisms, leveraging features like smart contracts and consensus algorithms such as PoA to enhance data integrity and transparency. Our analysis revealed that Ethereum's PoA consensus mechanism achieved an average transaction throughput of 1000 transactions per second, ensuring efficient data processing across distributed cloud infrastructures. Furthermore, the adoption of IPFS protocol introduces efficient data sharding and hashing mechanisms, optimizing data storage and retrieval processes while ensuring high availability and fault tolerance. Performance testing results indicated an average latency of 15 milliseconds for data retrieval operations, highlighting the protocol's effectiveness in supporting real-time data access requirements. Moreover, the utilization of cloud infrastructure components like OpenStack private cloud and Red Hat OpenShift provides flexible and scalable deployment options, enabling seamless integration of blockchain-enabled data governance frameworks. The findings showcased that OpenStack private cloud achieved an average CPU utilization of 75% and memory utilization of 65%, indicating efficient resource utilization for data processing tasks. Through performance testing and analysis, critical performance metrics such as throughput, latency, and resource utilization, which provide valuable insights into system efficiency and scalability, are observed.

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