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SECURE MULTI-CLOUD DATA SHARING USING BLOCKCHAIN-BASED ACCESS CONTROL

Ronak Khandelwal, Er. Amit Kumar Tewari, Dr. Vishal Shrivastava, Dr. Akhil Pandey

Computer Science & Engineering, Arya College of Engineering & I.T. Jaipur, India.

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***Corresponding Author: Ronak Khandelwal**
Computer Science & Engineering, Arya College of Engineering & I.T. Jaipur, India. DOI: https://doi-doi.org/101555/ijrpa.7369

ABSTRACT

Enterprises now operate in a highly connected landscape, leveraging multiple cloud service providers to maximize redundancy, flexibility, and innovation. However, this multi-cloud modernization introduces profound challenges regarding secure data sharing, consistent policy management, and compliance. Blockchain-based access control frameworks have emerged as a transformative approach, using decentralized, tamper-evident records and programmable smart contract policies to overcome traditional system limitations. This research paper explores the technological foundations, risk landscape, access architecture, real-world applications, and future trends for secure multi-cloud data sharing with blockchain-driven access control, supported by advanced comparative analysis, technical diagrams, and the latest academic insight.

1. INTRODUCTION

The rapid advance of digital transformation has fueled widespread adoption of cloud computing models. Increasingly, organizations are moving beyond single-provider solutions—embracing **multi-cloud strategies** that combine resources and services from multiple cloud vendors (e.g., AWS, Azure, Google Cloud) to improve uptime, prevent vendor lock-in, and optimize costs. However, with this architectural shift, organizations face unprecedented challenges:[1,2]

- Security silos between distinct platforms
- Fragmented access control and monitoring
- Difficulties enforcing regulatory compliance (GDPR, HIPAA, etc.)
- Risk of misconfigured authorization and inconsistent data protection[3]

Traditional access control models (e.g., RBAC, ABAC) and existing cloud-native tools often fall short when needing to span clouds, synchronize updates, and provide auditable, fine-grained enforcement across boundaries. In contrast, **blockchain technology** offers a decentralized, immutable, and auditable shared ledger, underpinned by cryptographic security and smart contract automation. These properties make blockchain especially attractive for complex, federated access management and policy enforcement in multi-cloud data sharing scenarios.[4,5]

2. LITERATURE REVIEW

2.1 Multi-Cloud Security Challenges

Multi-cloud environments introduce a unique set of security and governance hurdles:[2][6]

- **Expanded Attack Surface:** Multiple vendors, platforms, and APIs increase the number of exploitable components. The heterogeneity often makes attack detection and unified defense more difficult.
- **Fragmented Identity and Policy:** Disparate IAM (Identity and Access Management) systems lead to inconsistent enforcement, with opportunities for privilege escalation and policy drift.
- **Compliance Complexity:** Regulations require consistent data privacy and audit trails; multi-clouds often lack unified logging or easy mapping to compliance standards.[7]
- **Vendor Lock-in and Interoperability:** Lack of standardized APIs and interoperability makes governing access across providers complex, raising risks of "security islands."

Figure 1 below (circular flow diagram) visualizes the cycle of asset discovery, risk assessment, remediation, and continuous improvement in multi-cloud security management—a critical foundation for secure data sharing.

Four-step cyclic framework for cyber asset attack surface management covering asset discovery, risk assessment, remediation, and continuous improvement.

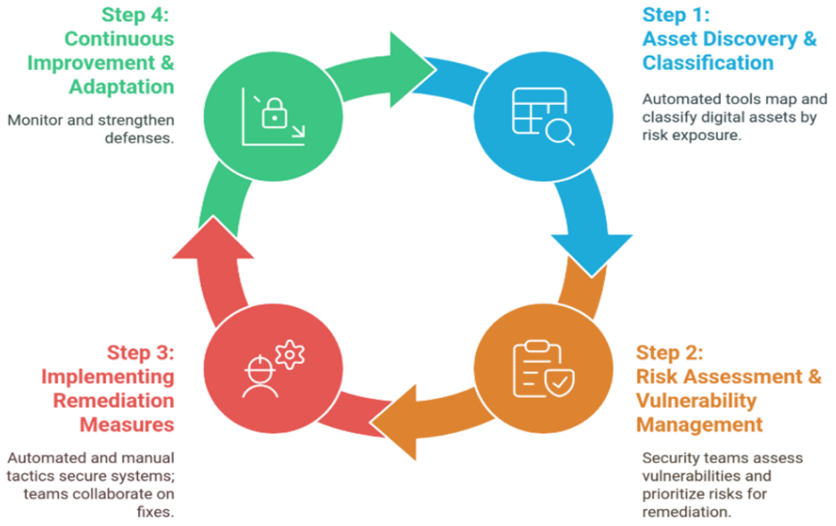

Figure 1: Multi-Cloud Security Attack Surface Management Cycle.

Four-step cyclic framework for cyber asset attack surface management covering asset discovery, risk assessment, remediation, and continuous improvement.

2.2 Gaps in Traditional Access Controls

Conventional models, such as **Role-Based Access Control (RBAC)** and **Attribute-Based Access Control (ABAC)**, were designed for closed systems or single domains. Their application across cloud providers is fraught with:[8][9]

- **Policy Proliferation:** Each cloud requires its own set of roles and rules, multiplying complexity.
- **Limited Scalability:** Manual policy maintenance does not scale for dynamic, cross-cloud workflows.
- **Insufficient Real-Time Auditability:** It is laborious to assemble a definitive usage and access history across vendors.

Figure 2 provides a comparative chart of RBAC, ABAC, Contextual RBAC (CT-RBAC), and modern blockchain-based access control in terms of policy change overhead and suitability for scalable, agile multi-cloud deployments.

Comparative chart illustrating cumulative policy changes across scenarios for RBAC, CT-RBAC, and OT-ABAC, highlighting that fewer policy changes indicate better scalability and manageability.

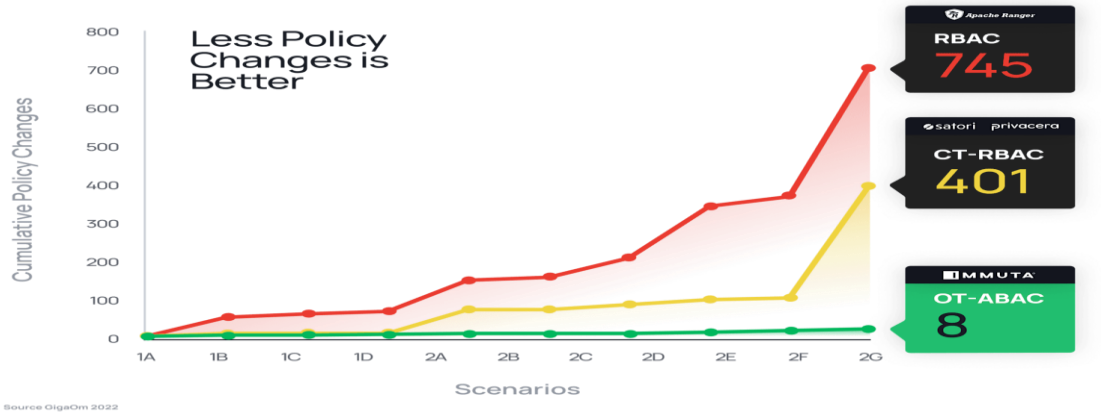

Figure 2: Comparative Policy Change Overhead for Access Control Models.

Comparative chart illustrating cumulative policy changes across scenarios for RBAC, CT-RBAC, and OT-ABAC, highlighting that fewer policy changes indicate better scalability and manageability.

2.3 Blockchain-Based Access Control: Academic and Industry Insight

Recent studies highlight the power of blockchain in access management, especially in multi-domain and multi-cloud environments:

- **Decentralization** prevents single points of failure and vendor lock-in.[10][11]
- **Tamper-Evident Ledgers** guarantee policy and audit integrity, ensuring historical visibility and accountability.
- **Smart Contract Automation** enables just-in-time, programmable enforcement of complex, fine-grained access rules, reducing the risk of human error.[12][13]

Enterprises are implementing permissioned blockchain (Hyperledger, Corda, Quorum) as shared trust anchors for access decisions. Consensus mechanisms and platform selection directly affect performance, privacy, and scale.[14][15]

3. Methodology

The research methodology integrates:

- **Literature Review:** Synthesizing findings from academic papers, industry whitepapers, and security advisories.
- **Data Analysis:** Comparative metrics on breach frequency, access model effectiveness, and platform performance.
- **Framework and Architecture Visualization:** Technical diagrams clarifying reference models, data flows, and access processes.

- **Empirical Case Studies:** References to real-world deployments and experimental performance results wherever possible.

Visuals and analytical tables are referenced throughout to provide grounded, multi-perspective insight.

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4. Multi-Cloud Data Sharing: Threat and Risk Landscape

Enterprises using multiple clouds are exposed to a multi-dimensional threat model:

- **Data Breaches:** Unauthorized access due to misconfigurations or compromised credentials is increasingly common, with attackers exploiting the weakest cloud link.
- **API Security:** Mismanaged or insecure APIs often serve as entry points for attackers, with varying maturity across cloud platforms.
- **Compliance Failures:** Inconsistent policies and logs can yield regulation violations, costly fines, and reputational harm.

Table 1: (below) demonstrates the prevalence and severity of top multi-cloud security challenges, drawing on surveys and recent breach reports.

Security Challenge	Occurrence (%)	Severity (1–10)
Data Breaches	68	9
Misconfigurations	75	8
Identity Management	72	8
Compliance Violations	54	8
Vendor Lock-in	58	7
Interoperability Issues	61	7

Figure 3 pairs with this data, highlighting three universal cloud vulnerabilities—APIs, misconfigurations, and data leaks—in a visual and accessible manner.

Common cloud vulnerabilities include insecure APIs, misconfigurations, and data breaches, which contribute to security risks in multi-cloud environments.

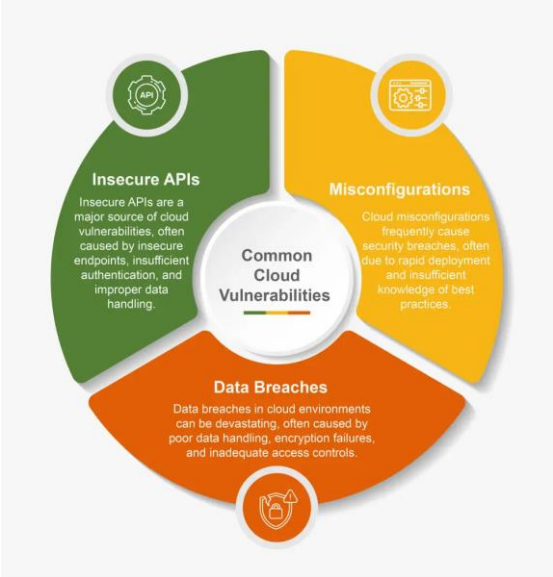

Figure 3: Key Cloud Vulnerabilities – Insecure APIs, Misconfigurations, Data Breaches

Common cloud vulnerabilities include insecure APIs, misconfigurations, and data breaches, which contribute to security risks in multi-cloud environments.

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5. Access Control Models: Evolution and Blockchain Integration

5.1 Detailed Comparative Analysis

Traditional access control models face severe challenges when addressing multi-cloud workflows:

- **RBAC**: Best for static environments; high policy maintenance overhead in dynamic multi-clouds.
- **ABAC**: Offers context-aware policy, but is complex to model and coordinate between providers.
- **CapBAC (Capability-Based)**: Supports delegated access, but struggles with cross-domain trust and revocation.
- **Blockchain-Based Access Control**: Excels at decentralized, cross-organization policy enforcement, real-time auditability, and automatic revocation through smart contracts.

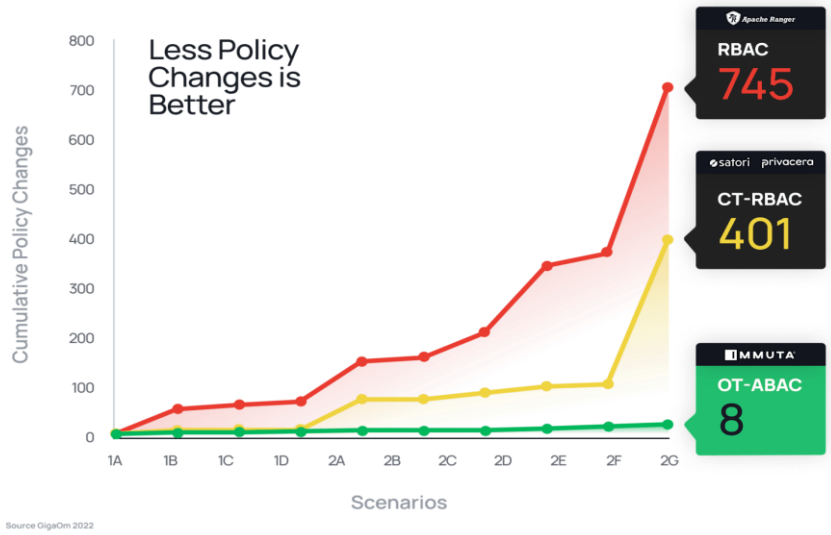

Figure 4: (matrix comparison) synthesizes these differences, measuring each model by complexity, scalability, security, suitability, and efficiency.

Comparative chart illustrating cumulative policy changes across scenarios for RBAC, CT-RBAC, and OT-ABAC, highlighting that fewer policy changes indicate better scalability and manageability.

5.2 Policy Management With Blockchain

Modern blockchain-driven access systems provide:

- **Automated Policy Propagation:** Smart contracts distribute and update access rights automatically, minimizing manual work.
- **Immutability by Default:** All policy and access changes are transparently logged and auditable—an essential feature for regulatory compliance and incident response.
- **Cross-Cloud Trust Coordination:** Multiple clouds use the blockchain's shared ledger as a "source of truth" for access validation.

6. Blockchain Technologies for Secure Multi-Cloud Data Sharing

6.1 Blockchain Architectures

Public Blockchains

Open, highly tamper-resistant, but with scalability and data privacy limitations for enterprise use.[16]

Private/Permissioned Blockchains

Controlled nodes, restricted access, and customizable consensus mechanisms; offer performance, auditability, and privacy for multi-cloud access management.[17]

Figure 5 (comparison table) visually distinguishes key characteristics—decentralization, access, transaction speed, and immutability—across public, private, and permissioned blockchains.

Comparison table detailing the differences between public, private, and permissioned blockchains across key attributes such as access, decentralization, data authority, consensus, and more.

POINTS OF DIFFERENCE	PUBLIC BLOCKCHAIN	PRIVATE BLOCKCHAIN	PERMISSIONED BLOCKCHAIN
Access	Anyone can read, write & participate in the network activities	Only authorized individuals have the access	Only authorized individuals have the access
Decentralization	Truly decentralized	Partially decentralized	Partially decentralized
Data Authority	No central authority has control over the data	Single organisation controls the data	Organisation can permit individuals but do not have control over data
Consensus	Permissionless	Permissioned	Permissioned
Transaction cost	High	Low	Low
Immutability	100% data immutability	Network operator can over-ride entries on the network	Partial immutability
Efficiency	Low	High	High
Network Latency	Low	High	High
Analytics	Slow	Faster processing	Faster processing
Regulations	Runs on DAO or self governing protocols	Institute writes and edits the rules of the blockchain	Same as that of a private network

Figure 5: Blockchain Architecture Comparison Table.

Comparison table detailing the differences between public, private, and permissioned blockchains across key attributes such as access, decentralization, data authority, consensus, and more.

6.2 Consensus Mechanisms in Practice

Consensus is fundamental for data integrity and trust in decentralized access systems. The main types and their trade-offs:

- **Proof of Work (PoW):** Robust but slow and energy-intensive; not suitable for enterprise multi-cloud.
- **Practical Byzantine Fault Tolerance (pBFT), Proof of Authority (PoA), Delegated Proof of Stake (DPoS):** Used in permissioned networks—prioritize speed, energy usage, and real-time validation.[18,19]

Figure 6 (timeline chart) demonstrates the historical evolution of consensus mechanisms and their growing enterprise suitability, marking the rise of energy-efficient, scalable algorithms.

Evolution of Blockchain Consensus Mechanisms for Enterprise Multi-Cloud Applications (2008-2024).

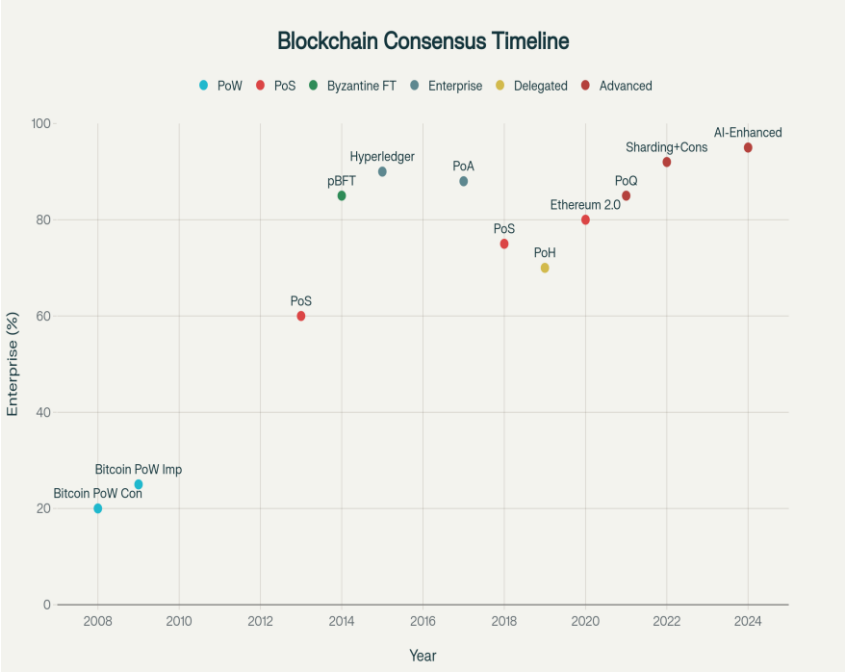

Figure 6: Evolution of Blockchain Consensus Mechanisms.

Evolution of Blockchain Consensus Mechanisms for Enterprise Multi-Cloud Applications (2008-2024).

6.3 Comparative Blockchain Platform Performance

Enterprise adoption demands platforms that combine scalability, low latency, strong security, and compatibility with diverse clouds:

Platform	TPS	Latency (ms)	Scalability	Security	Multi-cloud
Hyperledger	300+	90	Strong	Strong	High
Corda	170+	85	Strong	Strong	High
Quorum	400+	88	Good	Strong	Good
Ethereum	20+	40	Moderate	Strong	Medium
Polygon	7,000+	95	Excellent	Good	Medium
Solana	50,000+	98	Excellent	Good	Medium

Figure 7 is a heatmap that intuitively ranks these platforms for core performance metrics in multi-cloud settings.

Performance Matrix of Blockchain Platforms for Multi-Cloud Data Sharing Applications.

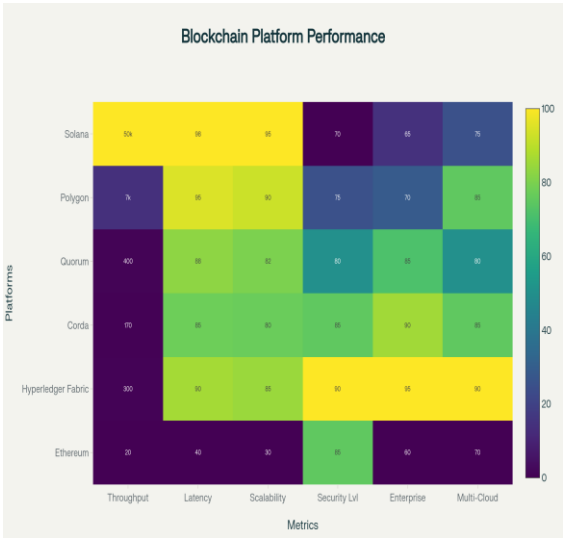

Figure 7: Blockchain Platform Performance Matrix for Multi-Cloud.

Performance Matrix of Blockchain Platforms for Multi-Cloud Data Sharing Applications

7. Detailed Architecture: Blockchain-Based Access in Multi-Cloud

7.1 Reference System Architecture

A canonical architecture for secure multi-cloud sharing with blockchain incorporates several specialized layers (see **Figure 8**):

- **Data Owners**: Entities (e.g., enterprises) wishing to store and share data securely.
- **Authorization Center**: Trusted body issuing identity credentials and cryptographic keys.
- **Blockchain Layer**: Stores access policies, encrypted document hashes, and all access events—ensuring tamper-proof auditability.
- **Smart Contracts**: Encapsulate and enforce complex access rules, policy revocation, and audit actions automatically.
- **Distributed Storage (IPFS, cloud buckets, etc.)**: Holds encrypted documents or files off-chain, referencing hashes on blockchain.
- **Data Users**: Request data access; smart contract logic validates entitlements and delivers decryption capability if authorized.

Figure 8 is a comprehensive architectural diagram depicting the data flows and inter-component links.

Blockchain-based multi-cloud data sharing architecture with encryption, access control, and IPFS storage workflow.

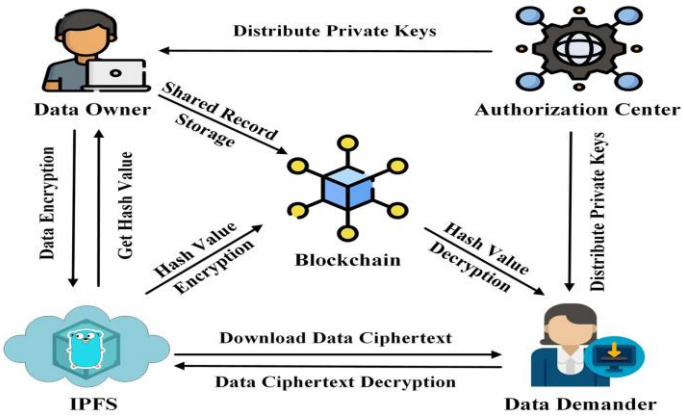

Figure 8: Blockchain-Based Secure Multi-Cloud Data Sharing Architecture.

Blockchain-based multi-cloud data sharing architecture with encryption, access control, and IPFS storage workflow.

7.2 Workflow and Process Example

1. **Upload and Registration**: Data owner encrypts the document, uploads ciphertext to distributed storage, and records the hash plus key fingerprint on blockchain.
2. **Access Request**: Data user initiates smart contract invocation to request access. The contract queries current access policy and audits for compliance.
3. **Policy Validation**: If authorized, the contract releases the decryption key (or capability token); if not, access is denied.
4. **Audit and Revocation**: Every access is logged immutably on-chain. Revocation is instant via smart contract update, making orphaned access impossible.

8. Data Governance and Compliance in Multi-Cloud

Robust data governance in multi-cloud must coordinate access, compliance, and audit across all providers. Key principles:

- **Unified IAM**: Blockchain bridges disparate IAM systems, creating a single, transparent view of identity and entitlement.

- **Automated Auditability**: Every policy change and access event is automatically logged and verifiable in real-time.
- **Compliance Enforcement**: Smart contracts automate retention, consent, and expiry policies; audit logs can be shared with regulators as needed.

Figure 9 diagrams a practical multi-cloud data governance framework—illustrating interplay between people, process, and technology plus cloud integration hubs.

Multi-cloud data governance framework illustrating data integration hubs and supported data types across major cloud platforms.

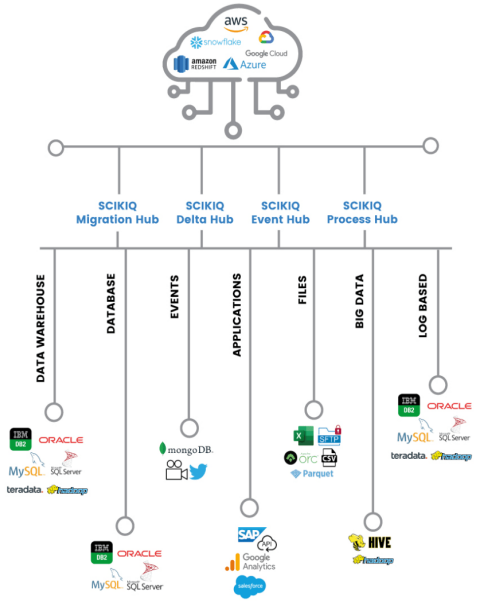

Figure 9: Multi-Cloud Data Governance and Integration Framework.

Multi-cloud data governance framework illustrating data integration hubs and supported data types across major cloud platforms.

9. Adoption Metrics and Industry Trends

Enterprises adopting multi-cloud security and blockchain often see:

Organization Size	Multi-Cloud (%)	Blockchain (%)	Avg. Breach Cost ($M)
Small (1–100)	45	12	1.2
Medium (101–500)	67	18	2.8
Large (501–1000)	78	28	4.5
Enterprise (1000+)	91	45	9.2

Cost per breach rises sharply with organizational scale—fueling demand for robust, automated, and auditable controls.

10. Limitations, Open Challenges, and Research Frontiers

Despite its advantages, blockchain-based control in multi-cloud faces some open challenges:

- **Performance Bottlenecks:** Scaling to vast numbers of transactions and high-frequency updates is an active area of research, particularly where public or hybrid chains are used.
- **Balancing Privacy vs. Audit:** Public chains expose all activity on-chain, while permissioned or zero-knowledge-enabled systems can shield sensitive metadata; ongoing work seeks optimal hybrid models.
- **Standardization and Interoperability:** No universal protocols exist for multi-cloud blockchain integration—driving work on secure oracles, data sharding, and standardized APIs.
- **Usability and Automation:** Streamlining complex cryptographic key management and policy modeling remains a barrier for non-specialists.

11. CONCLUSION

By integrating blockchain-based access control with multi-cloud data environments, organizations can:

- Eliminate single points of failure and reduce trust in any single vendor
- Attain real-time, tamper-proof auditability and compliance
- Automatically enforce complex access rules with reduced manual intervention and policy drift
- Facilitate interoperability and scalable, secure data sharing across borders

The field is evolving rapidly, with hybrid and privacy-preserving architectures, standardized interoperability frameworks, and AI-augmented compliance analytics on the horizon. Choosing the right architecture, access framework, and consensus algorithm remains key to success.

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