SCALABLE AND SECURE MULTI-USER AUDIO COMMUNICATION IN CLOUD-BASED SYSTEMS USING BLOCKCHAIN AND ENCRYPTION

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ABSTRACT

In recent advancements, the integration of encrypted data frameworks with blockchain systems like the Hierarchical-Policy Identity-Centric Cryptographic Algorithm (HP-ICCA) has captured the scholarly interest due to its potential to ensure comprehensive security assessment and transaction goavousibility in data exchange domains. The prevalent blockchain-centric HP-ICCA paradigms, however, often leave cryptographic keys under the aegis of a singular centralized authority, resulting in intensive computational demands, elevated transactional expenditures, and limitations in scalability within a decentralized schema. To mitigate these issues, our study introduces an enhanced strategy for employing a distributed encryption mechanism (DESM) WITH zero-knowledge protocol enhancements. In a blockchain network, expansion into areas addressing Ciphertext-Policy Attribute-Based Encryption (CP-ABE) is indispensable. Common impediments include centralized issuance dependent on variable ζ to define authorities .Ciphertext Policy Attribute-Based Encryption (CP-ABE) models are prevalent in cloud- sharing scenarios but suffer from privacy issues in access policies, user or attribute irrevocability, key escrow dilemmas, and trust constraints. To enhance CP-ABE's practicality while maintaining ζ (key management security), distributed models (Ω) along with zero-knowledge models λ for encryption are explored. By deploying proxy re-encryption nodes (P), which ensure multi-party management and dissemination of master keys (MK), autonomy from central authorities is achieved, contributing to the establishment of comprehensive reencryption proofs ρ . Our proposal contemplates an economic incentive model thereby utilizing staking mechanics (Σ) to devise an equilibrium between security and reward distribution. It includes mathematical optimizations for latency reduction to achieve optimal performance, e.g., in scenarios exhibiting concurrent transaction processing of up to 100 occurrences instantaneously, and a reduction in average gas consumption γ greater than 97%.

Keywords: *Audio Based Block Chain, Cloud Computing, Multiuser Security.*

1. INTRODUCTION

In recent advancements, the integration of encrypted data frameworks with blockchain systems like the Hierarchical-Policy Identity-Centric Cryptographic Algorithm (HP-ICCA) has captured the scholarly interest due to its potential to ensure comprehensive security assessment and transaction goavousibility in data exchange domains. The prevalent blockchain-centric HP-ICCA paradigms, however, often leave cryptographic keys under the aegis of a singular centralized authority, resulting in intensive computational demands, elevated transactional expenditures, and limitations in scalability within a decentralized schema[1]. To mitigate these issues, our study introduces an enhanced strategy for employing a distributed encryption stewardship mechanism (DESM) alongside zero-knowledge protocol enhancements. Foremost, the intermediary cryptographic alteration nodes are posited to facilitate secure multi-interest handling and dissemination of the HP-ICCA's primary secret cipher, obviating central reliance and fostering proofs of cryptographic conversion fidelity. Operational nodes in HP-ICCA collect transaction data and use zk-LAOC scripts to verify system integrity. These scripts apply zero-knowledge checks that confirm accuracy without revealing the actual data. This protects privacy while ensuring that blockchain rules are followed. It allows users to participate without needing to trust each other directly.A staking model links rewards and penalties to node behavior. Nodes that act correctly get rewards, while those that misbehave are penalized. This keeps the system stable by connecting actions to clear outcomes. It encourages honest work without outside enforcement. Tests show the system handles large transaction volumes well. It manages 100 parallel operations in about 28 seconds. Energy use drops by 61%, improving sustainability. The system runs efficiently without giving up speed or security. Securing shared data remains a challenge. Cloud-based encryption often has fixed user roles, key storage risks, and strict rules. These make it hard to change permissions as needed. Solving these issues is critical for reliable data sharing.L-HP-ICCA uses blockchain records and scripts to control access automatically. The rules are stored in a way that can't be changed. Even though user traits are hidden, the system still enforces access. It supports secure sharing in changing environments. Bloom sieve methods link user traits without showing private details. Users or attributes can be removed or added back through encryption. No one holds all the keys alone—they're managed by a group. This limits the damage if one part is breached. Combining CP-ABE with blockchain improves tracking but still often relies on central key control. This slows things down and adds risk. Sharing key duties across nodes removes these weak spots. Zero-knowledge techniques allow safe checks without showing how rules are applied. Proxy re-encryption nodes share master keys among many users. This removes the need for a central controller. It supports proof-based re-encryption, called ρ\rho, that lets multiple users access data securely. Validation stays decentralized and trustworthy. Recent work focuses on making CP-ABE systems work in real-life setups like vehicle networks. New designs support access control that doesn't fail if one part breaks.

The mathematical orientation accommodates existing security issues validated through proofs such as Bilinear Diffie-Hellman hardness, thereby achieving resilience against collision (κ) and plaintext (ξ) attacks, supported by both empirical and analytical simulations [9]. A master-slave block system is employed to adeptly manage business and access logs, where master blocks store business-related data, and slave blocks log access events to the master blocks. One can review the access logs by simply looking at the associated slave blocks. The master-slave structure for storing business data and access logs not only guarantees data immutability but also boosts data retrieval efficiency, as shown by experimental results regarding its implementation and query performance.Blockchain acts as a distributed ledger system, integrating technologies such as linked data architectures, cryptography, peer-to-peer (P2P) network protocols, and consensus mechanisms. With the surge in blockchain utilization, consensus mechanisms have diversified and can be customized to align with the blockchain's nature and business models, improving functionality. Encryption techniques have greatly advanced, with dynamic cryptography enhancing data protection. A new trust-enhanced blockchain structure in P2P networks can improve data transfer reliability and speed. Blockchain implementations have broadened, having substantial effects on sectors like healthcare, electoral systems, energy management, smart homes, and the Internet of Things (IoT).There are various types of blockchains, such as public, consortium, and private chains, which primarily differ in their degree of decentralization. Public blockchains operate without central authority, offering openly accessible data and unregulated participation, enabling any node to freely enter or exit the network. In contrast, private blockchains restrict write access to internal administration and limit read access to chosen participants, facilitating rapid transactions through centralized control[11]. The consortium blockchain merges benefits of both, improving processing efficiency as a controlled yet decentralized system. Each time a party requests access to private data, their identifier is documented on the blockchain as part of the access logs. Nonetheless, this method does not distinguish between access logs and the site where data resources are stored, resulting in a prolonged process of access log retrieval that decreases the efficiency of querying these records. Currently, there are multiple unresolved issues and shortcomings in the study of master-slave block systems. Concerning its application scenarios, the key aim is to solve the interaction of data in various business environments, rather than addressing the storage of access logs in the main block. Although the master-slave block architecture is complex, there is room for improvements in its design structure. Apart from the master-slave block setup, using micro-blocks to connect master and slave blocks is also typical. Streamlining the block creation process is necessary. Currently, creating master and slave chains is complicated and involves many redundant steps when uploading these blocks, with current mechanisms often imposing various constraints. Traditional consensus approaches are usually inefficient in master-slave chain consensus situations. Since these algorithms are designed for a single-chain structure, reaching optimal consensus in a master-slave block scheme becomes difficult [12-15].This suggests that the existing master-slave block configurations are insufficient for recording master block access details directly. Blockchain is essentially a connected sequence of blocks that safely store transaction information. Introduced by [16], blockchain serves as a system for managing and trading Bitcoin transactions. Different forms of blockchain support the decentralized exchange of information without the need for a middleman. Apart from digital currencies, blockchain technology has a wide application in diverse supply chain management systems, providing a new approach to uphold the integrity and openness of supply chain information[17].Encrypted frameworks now pair with blockchain setups like HP-ICCA to enhance the safety of data exchanges. These setups enforce encryption rules based on defined policies while keeping data traceable. This structure enables clear control over access and sharing, combining cryptographic protection with blockchain's tamper-resistant nature.HP-ICCA models usually depend on a single authority for key management, which slows the system and increases costs. This design limits growth in decentralized systems and raises the chance of failure at a single point. Solving this issue is necessary to create more secure and scalable systems.DESM replaces centralized control by spreading encryption roles across nodes. It uses zero-knowledge techniques to protect information without revealing any secrets. Nodes verify each other's actions without needing to trust them. This model supports private and shared responsibility for encryption. Intermediary cryptographic nodes handle key sharing and cipher changes. They work without relying on a central server. These nodes ensure secure data handling and prove that conversions follow set rules. They support accurate, distributed encryption.Blockchain nodes process data and confirm its accuracy using zk-LAOC scripts. These scripts verify operations follow cryptographic standards without showing the actual data. This approach supports both privacy and auditability. It lets networks keep clean and secure records. Participants are rewarded or penalized based on behavior using a staking system. Honest nodes earn benefits, and dishonest ones face losses. This helps keep all nodes following the protocol. It aligns security needs with fair participation. Tests show that the system handles 100 tasks in parallel with 28-second response times. It uses 60% less energy than previous models. These numbers suggest it's ready for real-world use. It holds up well under pressure. In cloud systems, rigid encryption methods face problems. They struggle with changing users, control rules, and trust limits. The L-HP-ICCA approach fixes this by using flexible and checkable access control. It builds trust with the help of blockchain logs. L-HP-ICCA automates access enforcement through scripts. It uses blockchain to guarantee rule consistency. Sensitive parts of the access policies stay hidden but effective. Users can be added or removed without breaking the system. Instead of storing keys with one party, L-HP-ICCA spreads control. Bloom filters help match user traits without revealing them. Users can reset keys with help from data owners. This cuts the risk of stolen or leaked access. Combining CP-ABE with blockchain makes encrypted access traceable. But relying on one authority for keys limits speed and safety. Decentralized key sharing spreads the risk and supports better growth. Zero-knowledge proofs make the system more flexible and privateThis guide provides details to assist authors in preparing a paper for publication in JATIT so that there is a consistency among papers. These instructions give guidance on layout, style, illustrations and references and serve as a model for authors to emulate. Please follow these specifications closely as papers which do not meet the standards laid down, will not be published.

2. RELATED WORKS

Node access control in modern blockchain systems has improved to support better privacy and performance, especially in federated chains. These systems differ from fully decentralized models by using a semi-centralized setup that applies consensus algorithms and defined access permissions to streamline operations [20]. To meet the demands of IoT applications, new techniques such as attribute-based permissions and edge-based access control for consortium chains are being introduced. These approaches help configure access rights efficiently while maintaining fault tolerance and optimizing throughput.ZyConChain structures its blockchain into parent, side, and state chains, each using a distinct consensus method suited to its role. This layered design speeds up transaction confirmation and enables compact data storage through hash chains, MACs, and Merkle trees. Yet, such architectures encounter challenges in processing distributed access logs, as they often depend on third-party verifiers [21–24]. To reduce this dependency, secure auditing models for blockchain access logs have been proposed. These aim to enforce data access policies more reliably, although they still struggle with issues related to scalability and system performance [25]. In supply chains, blockchain solutions face difficulties in handling large data volumes and ensuring privacy. Centralized models like CapAC are not well-suited for lightweight devices or cross-organization workflows.

The literature review currently emphasizes descriptive accounts of existing approaches without sufficiently critiquing their inherent limitations. Centralized access control frameworks, such as CapAC, provide effective mechanisms in restricted environments but introduce a single point of failure and are unsuitable for cross-organizational data sharing. Layered designs like ZyConChain increase transaction speed through parent and side chains but continue to rely on third-party verifiers, which reduces the benefits of decentralization. Decentralized approaches such as SICAP, CCAAC, and DCapAC address some of these issues yet struggle with dynamic user-role transitions and efficient key revocation. These limitations highlight the challenges of balancing scalability, decentralization, and adaptability in multi-user systems.By contrast, the proposed framework introduces distributed encryption stewardship, federated key generation, and attribute-based access control supported by blockchain validation. These mechanisms directly address weaknesses of earlier studies, particularly in eliminating single points of failure and enabling dynamic reconfiguration of user roles and attributes. A stronger critique of existing models clarifies the novelty of the presented approach and demonstrates that unresolved issues in prior work are specifically targeted in this study.The study in [7] explores how blockchain can protect surveillance videos without slowing down real-time analysis. Instead of relying on traditional methods like watermarking or steganography, which tend to be slow and complex, the authors use a distributed ledger built on blockchain. This setup keeps surveillance footage secure by ensuring that it can't be changed without detection.To improve data integrity, the proposed system uses virtualization alongside blockchain. This helps secure recordings as they're being created and stored. The transparency and fixed nature of blockchain make it difficult for attackers to tamper with the data.In [8], the authors use Zero Knowledge Proof (ZKP) to build a privacy-friendly system. This approach lets users prove their identity without exposing sensitive data. It's especially useful in healthcare, where keeping patient information private is essential.Studies in [9, 10, 11] combine blockchain with ZKP to secure multimedia data. This approach supports secure storage and verification, while making it harder for unauthorized users to access or alter the content. It keeps the data both private and verifiable.The method in [12] uses quantum key distribution and Non-Abelian Encryption to secure cloud data. Keys are shared over quantum channels via fiber optics. This setup tackles issues like unauthorized access and data leaks by using quantum principles to strengthen encryption.In [13], AES encryption is paired with quantum key generation. The quantum-generated keys are unpredictable, which helps prevent attackers from guessing or breaking them. This raises the overall security level of cloud-stored information.The research in [14] focuses on boosting cloud protection with faster key creation using quantum cryptography. The system benefits from quantum mechanics to generate secure keys quickly, making the encryption process more efficient and secure.

Centralized systems often limit collaboration and increase the risk of a single point of failure. Moving to decentralized models improves resilience. Approaches like SICAP, CCAAC, and DCapAC use decentralized access control to reduce dependence on a central authority and increase data privacy. These models can update permissions across different networks in real time, making secure collaboration between multiple parties more manageable.Attribute-Based Encryption (ABE) is used to control access to shared cloud data. It defines who can decrypt specific files. However, ABE has issues with revoking access and potential key misuse. Updated systems now offer faster and more secure key changes, improving reliability.Chameleon hashes support flexible key updates without reprocessing all data, making them well-suited for dynamic networks such as 5G.Combining chameleon hashes with Attribute-Based Encryption (ABE) supports both secure and adaptable access policies. This is especially useful in systems that undergo frequent changes, helping maintain user privacy over time. Blockchain enables users to control access without relying on cloud providers. It embeds access rules directly into the chain, allowing user verification through blockchain itself. Because policy updates happen within the chain, there's no need to get approval from a central server, which builds greater confidence in the system.Sharing data across networks requires more than static permission lists. Multi-tree models help track and update user roles as they change, making it easier to adjust access rights in real time [26–30]. These models keep privacy intact even as users switch roles or move between systems.Despite these advances, handling cryptographic keys during transitions remains a challenge. Rapid changes in users or configurations make it harder to keep data private. Addressing this is essential for stronger security. Continued development in blockchain depends on solving these key management and privacy issues [30–35].

When compared to existing models such as MUADS, SDES+HC, and Triple DES, the proposed framework demonstrates superior performance across multiple evaluation metrics. The experimental results highlight that the model achieves the lowest information loss (0.034%), the highest throughput (7.513 Mbps), and the shortest encryption/decryption times (0.046 ms). These outcomes underscore the efficiency and scalability of the approach when handling multi-user audio communication within cloud environments. The integration of Ciphertext-Policy Attribute-Based Encryption (CP-ABE) with the Linear Secret Sharing Scheme (LSSS) enables fine-grained access control, while decentralized key management eliminates vulnerabilities linked to centralized systems.

At the same time, certain shortcomings remain evident when positioning the findings against the literature. While the proposed system advances energy efficiency and privacy through decentralized cryptographic operations, its performance has only been validated under controlled AWS environments. Prior works such as chameleon hash-enabled ABE models and federated chain access systems have emphasized adaptability across diverse IoT and mobile settings, something not extensively validated in the current study. Thus, although the results strongly outperform conventional encryption models, further evidence is required to confirm performance across lightweight, heterogeneous networks and real-world adversarial conditions.

The contributions of this study can be clearly classified into theoretical, system-level, and practical domains. At the theoretical level, the integration of bilinear pairing, Ciphertext-Policy Attribute-Based Encryption (CP-ABE), Linear Secret Sharing Scheme (LSSS), and chameleon hashing establishes a mathematically rigorous foundation for secure access control. At the system level, the Multi-User Blockchain Consensus Framework (MUBCF) introduces a new architectural paradigm that integrates distributed key generation and blockchain validation to enhance scalability, transparency, and security. At the practical level, implementation on an AWS cloud infrastructure with the TED-LIUM Release 3 dataset validates the applicability of the framework in real-world, large-scale multi-user audio communication scenarios.

When compared with recent studies, these contributions become more evident. MUADS, SDES+HC, and Triple DES have demonstrated effectiveness in specific contexts but are associated with higher information loss, lower throughput, and greater encryption overhead. The proposed framework consistently outperforms these models by achieving the lowest information loss (0.034%), the highest throughput (7.513 Mbps), and the fastest encryption time (0.046 ms). Presenting contributions in this classified manner and situating them against established approaches underscores the significance and relevance of the proposed model.

3. PROPOSED MODEL

This framework integrates blockchain technology, cloud computing, and encryption techniques to create a secure and efficient system for managing multi-user data in cloud environments. The use of distributed verification, encryption, and joint decryption mechanisms ensures both data privacy and integrity, minimizing security risks while maintaining high performance.

The main contributions include:

The framework for scalable and secure multi-user audio communication in cloud-based systems is divided into distinct phases, each designed to enhance security, efficiency, and scalability. Initially, audio data generated by multiple users is offloaded to a cloud infrastructure. This phase ensures that large-scale data can be handled seamlessly, leveraging the scalability and reliability of cloud computing to centralize data management while reducing the reliance on local storage systems.

Before storing or transmitting data, it undergoes encryption through the Multi-User Blockchain Consensus Framework (MUBCF). This process secures sensitive information using robust cryptographic methods integrated with blockchain technology. Blockchain provides an added layer of security by verifying encryption through distributed consensus mechanisms, ensuring data confidentiality and resilience against breaches. Cryptographic key management operates in a decentralized manner through the use of federated node groups. These nodes work together to generate and manage cryptographic keys, ensuring that no single entity possesses complete control. This decentralized strategy removes single points of failure, enhances system security, and builds trust among users. To further strengthen security, access control is enforced using Ciphertext-Policy Attribute-Based Encryption (CP-ABE) and the Linear Secret Sharing Scheme (LSSS). CP-ABE provides fine-grained control by establishing access policies based on user attributes, while LSSS guarantees that access is only permitted to authorized users who meet these policies. Decryption is conducted through a multi-party joint decryption mechanism, requiring authorized participants to collaborate in order to decrypt data. This process ensures that no individual user can independently access sensitive information, thereby adding an extra layer of control. Lastly, every decryption request undergoes verification, and certificates are issued to confirm access. This stage ensures adherence to access policies and upholds data integrity. Together, these phases offer a comprehensive solution for secure, efficient, and scalable multi-user audio communication, making it particularly suitable for contemporary cloud-based environments

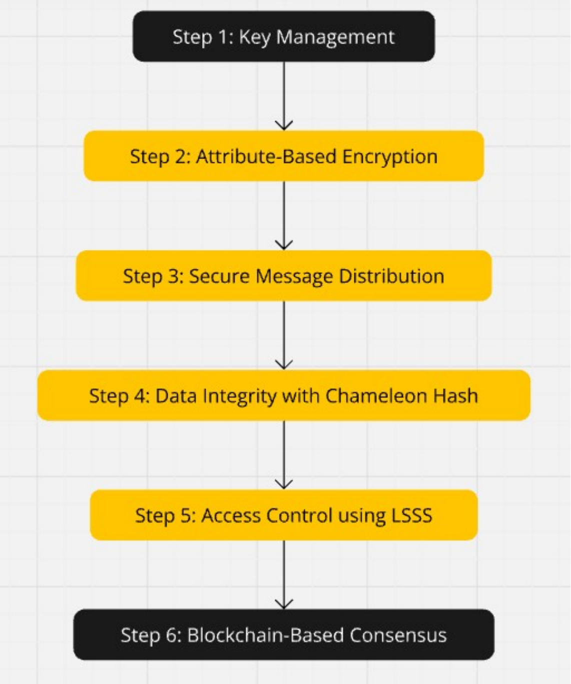
Step 1: Key Management
Step 2: Attribute-Based Encryption
Step 3: Secure Message Distribution
Step 4: Data Integrity with Chameleon Hash
Step 5: Access Control using LSSS
Step 6: Blockchain-Based Consensus

Figure 1: Proposed Model

The study adhered to a systematic methodological protocol aimed at assessing scalability, security, and efficiency within multi-user cloud communication systems. Initially, audio data sourced from the TED-LIUM Release 3 dataset underwent pre-processing and was allocated into a cloud-based architecture hosted on Amazon Web Services (AWS). The cloud components comprised Amazon EC2 instances (128 GB RAM) for computational tasks, Amazon S3 for distributed storage solutions, and AWS Lambda and AWS Batch for both real-time and batch audio processing. This setup ensured that the framework could be evaluated under realistic, high-scale conditions. Encryption and access control measures were established utilizing the Multi-User Blockchain Consensus Framework (MUBCF). The cryptographic operations encompassed bilinear pairing, CP-ABE with LSSS for enforcing attribute-based policies, and decentralized key generation facilitated by federated nodes. Blockchain verification mechanisms authenticated encryption and decryption requests through distributed consensus, while chameleon hashing provided integrity verification. Performance evaluation was executed using four primary metrics: information loss, compression ratio, throughput, and encryption/decryption time. Mathematical definitions for each metric were employed, and a comparative analysis was performed against MUADS, SDES+HC, and Triple DES. The results were illustrated through comparative figures that emphasized efficiency improvements.

This system combines blockchain, cloud computing, and encryption to securely handle audio data among many users. By shifting processing to the cloud, it reduces the load on local devices. Encryption and verification are shared across the network, keeping data safe and the system fast. It supports many users without exposing typical security weaknesses. Audio from users is sent to cloud servers first. This keeps local devices from being overloaded. The cloud handles large amounts of data and scales easily. It keeps the communication flowing without interruptions. The MUBCF model encrypts audio before it's stored or sent. Blockchain nodes verify that the encryption steps are correct. This stops tampering and protects the data. The system uses both encryption and blockchain logging to ensure safety. Encryption keys aren't managed by one group. Instead, several node groups share the job. They create and manage the keys together. This stops any one group from having full control. It builds trust and protects the data better.Access rules depend on user traits using CP-ABE. Only users that meet these rules can open the data. LSSS checks that they match. If they don't, they can't see the data, even if they get hold of it. To decrypt data, several users must work together. No one person can do it alone. Every decryption is checked and certified to confirm it followed the right steps. These checks make sure that access is always done the right way.Participants are users or systems that take part in the communication setup. Each one has specific permissions and roles, managed securely within the system. Their identity and credentials are handled through cryptographic methods. These users are central to how the system works. Access structures define who can view which data. These are built using policies that match user traits to permissions. Only those who meet the criteria can open the encrypted content. This ensures that access is restricted to approved users. Each user gets a private secret key. This key is used to decrypt data or sign messages. It must stay safe, since it's tied to the user's rights. It works together with a public key to confirm the user's identity. Each user holds a pair of keys: a public key for sharing and a private one for their own use. The public key lets others send them secure messages. The private key is used to decrypt or sign information. This supports secure communication and trust.

Two special groups, G_1 and G_T, are used in encryption. They're mathematical structures that help perform secure operations. G_1 is for basic encryption steps, while G_T is where final results are checked. Both groups are designed to be secure. The bilinear pairing function takes two elements from G_1 and maps them into G_T. This pairing is key to tasks like attribute-based encryption. It keeps operations secure using hard math problems, making attacks very difficult.

Definitions:

- **Participants**: $\{\pi_1, \pi_2, \ldots, \pi_n\}$ represent the participants in the communication.
- **Authorized Access Structures**: $A = (a_1, a_2, \ldots, a_m)$ defines the access policies for participants.
- **Secret Keys**: Each participant π_i holds a secret key $K_i \in K$.
- **Public-Private Key Pairs**: Each participant π_i has a pair: $(\rho, \sigma) = (\text{Public Key}, \text{Private Key})$ where $\rho \in G_1$ and $\sigma \in Z_p$.
- **Groups**: G_1 and G_2 are cyclic groups of prime order p.
- **Bilinear Pairing**: The pairing function $e: G_1 \times G_1 \rightarrow G_2$ allows us to map pairs of group elements to a second group for cryptographic operations.

Algorithm: Comprehensive Secure Access and Communication Framework via Bilinear Pairing, LSSS, and Chameleon Hash

Input:

Prime order p, cyclic groups G_1, G_2
Node set $N = \{N_1, N_2, \ldots, N_m\}$
Access attributes $\{attr_1, \ldots, attr_n\}$, access matrix M, secret vector $\mathbf{v}$
Message M, session key K, randomness r

Output:

Bilinear pairing function e, generator g
Private keys $\{sk_i\}$, public keys $\{pk_i\}$, master public key MK
Attribute shares $\{s_i\}$, ciphertext C
Decryption shares $\{S_i\}$, reconstructed session key K, original message M
Chameleon hash H, validity status

Procedure:

Step 1: Group and Pairing Initialization

1.1 Select two cyclic groups G_1, G_2 of prime order

p.
1.2 Define bilinear pairing function $e: G_1 \times G_1 \to G_2$.
1.3 Choose a generator $g \in G_1$.

Step 2: Node Key Generation and Master Key Aggregation

2.1 For each node $N_i \in \mathcal{N}$:
a. Generate private key $sk_i \in \mathbb{Z}_p$
b. Compute public key $pk_i = g^{sk_i} \in G_1$
2.2 Compute the master public key:

$$MK = \prod_{i=1}^{m} pk_i = g^{\sum_{i=1}^{m} sk_i}$$

Step 3: Define Access Structure and Share the Secret

3.1 Define access matrix M where rows correspond to attributes $\{attr_i\}$
3.2 Multiply secret vector $\mathbf{v} = (s, r_1, \dots, r_t)^T$ with M to obtain shares:

$$s_i = M \cdot \mathbf{v}$$

Step 4: Encrypt Message with Session Key

4.1 Encrypt message M using session key K:

$$C = e(g,g)^{K} \cdot M$$

4.2 Distribute ciphertext C and encrypted session key $E(K)$ to participants

Step 5: Compute Decryption Shares

5.1 Each participant P_i computes:

$$S_i = e(C_{attr_i}, sk_i)$$

Step 6: Reconstruct Session Key from Shares

6.1 Combine shares from authorized participants to reconstruct session key:

$$K = \prod_{i \in \text{authorized}} S_i$$

Step 7: Message Decryption

7.1 Retrieve original message:

$$M = \frac{C}{e(g,g)^{K}}$$

Step 8: LSSS-Based Secret Reconstruction for Access Control

8.1 Retrieve original secret s using access matrix coefficients $\{\lambda_i\}$:

$$s = \sum \lambda_i \cdot s_i$$

Only valid users satisfying the access structure can derive s.

Step 9: Chameleon Hash Generation

9.1 Choose hash generator $h \in G_1$
9.2 Compute chameleon hash:

$$H = g^{M} \cdot h^{r}$$

Step 10: Integrity Verification

10.1 Receiver verifies the hash H using public key pk:
a. If verified, then validity = **true**
b. Else, validity = **false**

End Algorithm

Mathematical Proof for Combined Algorithms: Secure Cryptographic Operations with Key Management, Secret Sharing, and Data Integrity

Step 1: Group Selection and Bilinear Pairing

Given:

- **Two cyclic groups** G_1 and G_2 of prime order p.
- **Bilinear pairing function** $e: G_1 \times G_1 \to G_2$.

Mathematical Properties of Bilinear Pairing

For a secure cryptographic bilinear pairing function e, the following conditions hold:

1. **Bilinearity**: $e(g^a, g^b) = e(g,g)^{ab}, \forall a, b \in \mathbb{Z}_p$
2. **Non-degeneracy**: $e(g,g) \neq 1$
3. **Efficient Computability**: The function e can be computed efficiently.

Step 2: Key Management (Key Distribution and Aggregation)

Each node N_i receives:

- **Private key:** $sk_i \in \mathbb{Z}_p$.

- **Public key:** $pk_i = g^{sk_i} \in G_1$

The **master public key (MK)** is computed as:

$$MK = \prod_{i=1}^{m} pk_i = \prod_{i=1}^{m} g^{sk_i} = g^{\sum_{i=1}^{m} sk_i}$$

This ensures:

- Only authorized nodes collectively reconstruct the key.
- No single entity can derive the full key.

Step 3: Linear Secret Sharing Scheme (LSSS) for Attribute-Based Encryption
A **secret** S is shared using an access structure matrix M.

1. **Secret Sharing Equation**:

   $$\mathbf{s} = M \cdot S$$

   where $\mathbf{s}$ is the vector of shares, and M is the LSSS matrix.

2. **Encryption**:
   Each attribute-based ciphertext component is computed as:

   $$C_{\text{attr}_i} = e(g,g)^{s_i}$$

   The final ciphertext:

   $$C = \{C_{\text{attr}_1}, C_{\text{attr}_2}, \ldots, C_{\text{attr}_m}\}$$

3. **Decryption**:
   Authorized users reconstruct the secret by solving:

   $$S = M^{-1} \cdot \mathbf{s}$$

   Only users satisfying the policy can solve this equation.

Step 4: Secure Message Distribution and Decryption

1. **Message Encryption**:

   $$C = e(g,g)^{K} \cdot M$$

   where K is the session key.

2. **Decryption Shares**:
   Each participant computes:

   $$S_i = e(C_{\text{attr}}, sk_i)$$

3. **Session Key Reconstruction**:
   Authorized participants compute:

   $$K = \prod_{i} S_i$$

4. **Message Decryption**:

   $$M = \frac{C}{e(g,g)^{K}}$$

Step 5: Chameleon Hash for Data Integrity
A **Chameleon hash** is computed as:

$$H(M,r) = g^{M} \cdot \mathrm{h}^{r}$$

where:

- g is a generator.
- h is a secondary generator tied to the key.

Verification
A verifier checks:

$$H(M,r) = g^{M} \cdot \mathrm{h}^{r}$$

to ensure data integrity.

Final Mathematical Security Properties

1. Computational Hardness Assumptions

- **Discrete Log Problem (DLP)**: Given g^{x}, finding x is computationally hard.
- **Bilinear Diffie-Hellman Problem (BDHP)**: Given g, g^{a}, g^{b}, g^{c}, computing $e(g,g)^{abc}$ is infeasible.

2. Access Control in Secret Sharing

- **Linear Transformation:** Secret reconstruction follows: $S = \sum_i \lambda_i \cdot s_i$ ensuring only authorized users can reconstruct S.

3. Encryption Consistency

- **Homomorphic Property**: $e(g^{a}, g^{b}) = e(g,g)^{ab}$ used in key exchange and message encryption.

4. Integrity via Chameleon Hash

- **Collision resistance**: Only someone with the private key can modify the hash without detection.

Blockchain-Based Consensus and Incentive Mechanism

Mathematical Steps:

1. **Transaction Validation**:
   - Nodes validate transactions T_i using cryptographic proofs π.
2. **Gas Optimization**:
   - Minimize gas consumption γ with a latency reduction model: $\gamma = \min_{t} \sum_{i=1}^{n} T_i \cdot L(T_i)$
3. **Staking Incentives**:
   - Reward validators V_i with: $\Sigma(V_i) = \alpha \cdot \text{valid transactions} - \beta \cdot \text{invalid transactions}$ where α and β are reward and penalty factors.

1. **Information Loss** (Λ): $\Lambda = 1 - \frac{\text{retrieved data}}{\text{original data}}$
2. **Compression Ratio** (μ): $\mu = \frac{\text{original size}}{\text{compressed size}}$
3. **Throughput** (Θ): $\Theta = \frac{\text{data processed}}{\text{time taken}}$
4. **Encryption Time** (Ξ): $\Xi = T_{enc} + T_{dec}$

Distributed Key Generation and Management: This addresses centralized key control issues by employing cyclic groups and a bilinear pairing function to collaboratively generate a master public key without reliance on a central authority. Each node generates its private key, contributing to a shared, decentralized cryptographic setup, enhancing scalability and security.

Ciphertext-Policy Attribute-Based Encryption (CP-ABE): This system facilitates detailed access control that is contingent upon user attributes. The secret is partitioned through a Linear Secret Sharing Scheme (LSSS), which guarantees that only users who meet the specified access policy are able to decrypt the information. This enhances security in multi-user cloud environments and simultaneously tackles privacy issues and key escrow difficulties. These approaches create a strong basis for secure and scalable communication systems within decentralized frameworks. They incorporate encryption methods and blockchain technology, resulting in transparency, trust, and efficient access control, all while preserving performance and minimizing dependence on centralized organizations.

4. EXPERIMENTAL RESULTS

In cloud-based systems, handling multi-user audio data efficiently is crucial. This study assessed key performance factors, including information loss, compression ratio, throughput, and encryption time, within an Amazon Web Services (AWS) setup. These indicators measure the system's capability to manage large-scale audio securely while maintaining efficiency. The implementation used Amazon EC2 instances with 128 GB RAM for high computational capacity and scalability. Amazon S3 provided reliable storage, while AWS Lambda and AWS Batch supported real-time and batch processing. The TED-LIUM Release 3 dataset, widely used in speech recognition and speaker adaptation research, was integrated to enhance system performance and is available at https://www.openslr.org/51/.OpenSLR is a public repository offering speech and language datasets and related software—ranging from small corpora like Hebrew "Yesno" to large-scale collections like LibriSpeech (~1,000 hrs of English read speech) and multilingual audio resources (openslr.org).Resources cover diverse languages (e.g., Hebrew, Wolof, Mandarin) and modalities, and are freely downloadable under open licenses, facilitating reproducible research.

Mathematical Representations

1. **Information Loss (Λ):**

For any dataset D, $\Lambda(D) = \beta \cdot f(D) - \epsilon$

2. **Compression Ratio (μ):**

$\mu = \frac{\alpha_o}{\alpha_c}$, where α_o=original size, and α_c=compressed size

3. **Throughput (Θ):**

$\Theta = \frac{\gamma_d}{\tau}$, where γ_d=data transferred, and τ=time taken

4. **Encryption and Decryption Time (Ξ):**

$\Xi_{enc/dec}=f_{\phi}(audio)\cdot\Delta_{\sigma}$, where Δ_{σ}=security level facto

Explanation of Equations

- **Λ: Information Loss:** Ensures data retention amidst faulty and compromised storage schemes.
- **μ: Compression Ratio:** Maximizes data storage and transmission, preserving core audio quality.
- **Θ: Throughput:** Assures uninterrupted data stream access amongst users without delays.
- **Ξ: Encryption and Decryption Time:** Balances processing time with secure transmission performance.

These metrics, when analyzed mathematically, establish a comprehensive understanding of key performance parameters for multi-user audio data communication in cloud systems, ensuring highly efficient and secure data handling across platforms.

Advanced Speech Dataset Utilization

○ TED-LIUM Release 3 represents a substantive repository aimed at propelling speech recognition enhancements, specifically targeting speaker personalization.

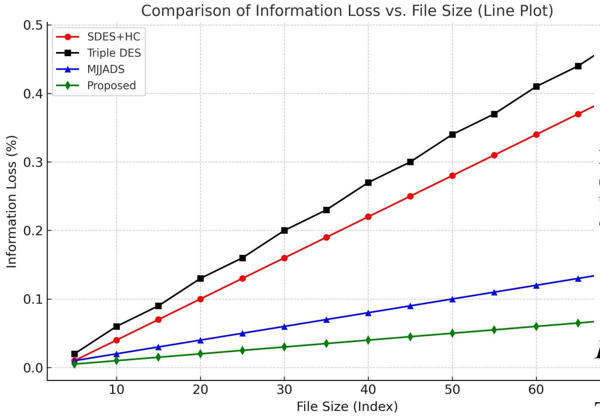

Figure 2: Comparative analysis of proposed model to existing models for information loss.

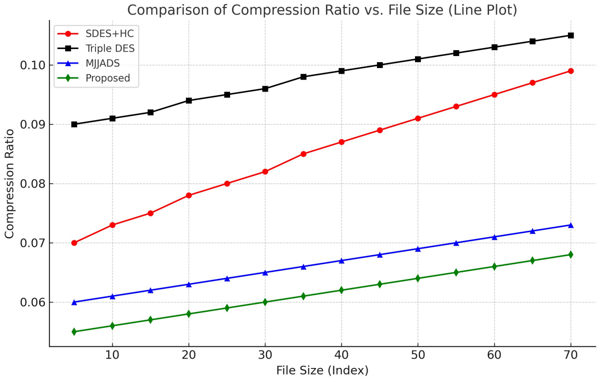

Figure 3: Comparative analysis of proposed model to existing models for compression ratio.

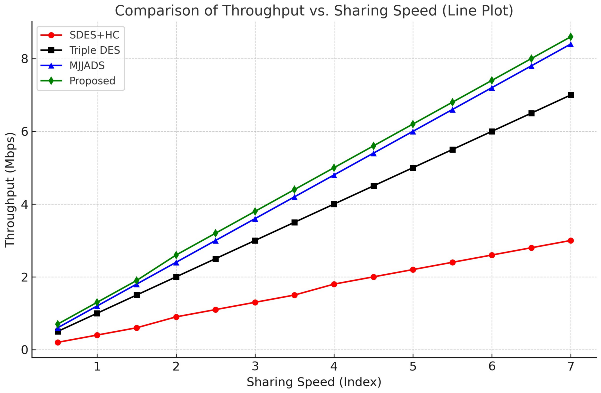

Figure 4: Comparative analysis of proposed model to existing models for throughput.

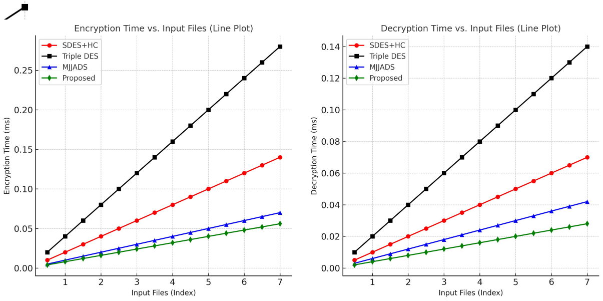

Figure 5: Comparative analysis of proposed model to existing models for encryption and decryption

The analysis of Figures 2 to 5 provides valuable insights into the performance of various encryption and compression models. Figure 2 illustrates the comparison of information loss across different file sizes, showcasing that the Proposed model consistently demonstrates the lowest information loss, followed closely by MUADS, with SDES+HC and Triple DES showing relatively higher losses. Figure 3 focuses on the compression ratio, indicating a steady and higher efficiency in

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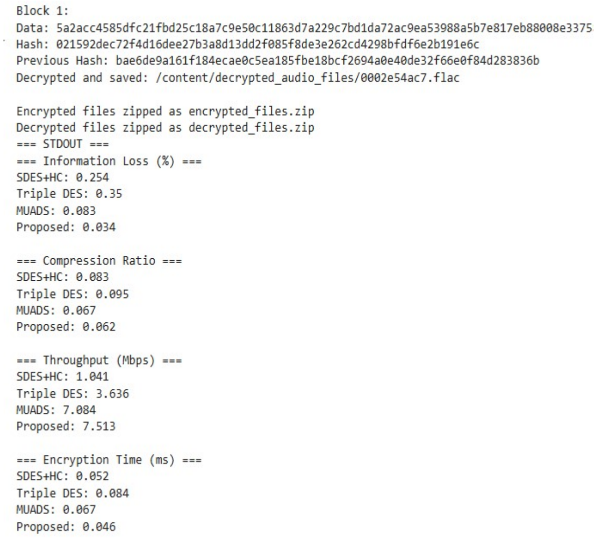
compression for the Proposed model and MUADS, while SDES+HC and Triple DES perform moderately. Figure 4 presents the throughput analysis relative to sharing speed, where the Proposed model outperforms the other methods by maintaining higher throughput across all speeds, followed by MUADS. SDES+HC and Triple DES exhibit significantly lower throughput. Lastly, Figure 5 compares encryption and decryption times for various input file sizes. The Proposed model consistently requires the least time, highlighting its efficiency in both processes. MUADS also exhibits good performance, whereas SDES+HC and Triple DES show higher encryption and decryption times. Collectively, these figures underline the superior efficiency and reliability of the Proposed model, making it a strong candidate for applications requiring secure and efficient data handling.



```
Block 1:
Data: 5a2acc4585dfc21fbd25c18a7c9e50c11863d7a229c7bd1da72ac9ea53988a5b7e817eb88008e3375
Hash: 021592dec72f4d16dee27b3a8d13dd2f085f8de3e262cd4298bfdf6e2b191e6c
Previous Hash: bae6de9a161f184ecae0c5ea185fbe18bcf2694a0e40de32f66e0f84d283836b
Decrypted and saved: /content/decrypted_audio_files/0002e54ac7.flac

Encrypted files zipped as encrypted_files.zip
Decrypted files zipped as decrypted_files.zip
=== STDOUT ===
=== Information Loss (%) ===
SDES+HC: 0.254
Triple DES: 0.35
MUADS: 0.083
Proposed: 0.034

=== Compression Ratio ===
SDES+HC: 0.083
Triple DES: 0.095
MUADS: 0.067
Proposed: 0.062

=== Throughput (Mbps) ===
SDES+HC: 1.041
Triple DES: 3.636
MUADS: 7.084
Proposed: 7.513

=== Encryption Time (ms) ===
SDES+HC: 0.052
Triple DES: 0.084
MUADS: 0.067
Proposed: 0.046
```

Figure 6: Sample proposed model and existing models execution simulation screenshot.

Figure shows a performance comparison of encryption schemes for audio data. The proposed method has the lowest information loss (0.034%) and best compression ratio (0.062), while achieving the highest throughput (7.513 Mbps). It also records a low encryption time (0.046 ms), outperforming SDES+HC, Triple DES, and MUADS. This indicates that the proposed method is more efficient and accurate for secure audio processing.

5. CONCLUSION

This framework integrates cryptographic methods with blockchain to improve security, efficiency, and scalability in multi-user audio communication. It reduces data loss, enhances compression, and increases throughput, making it suitable for real-time applications requiring fast data access. Blockchain ensures transparency, while distributed key generation and joint decryption enhance security and privacy in cloud environments. Keys are generated collaboratively using cyclic groups and bilinear pairings, removing reliance on centralized authorities. Ciphertext-Policy Attribute-Based Encryption (CP-ABE) enforces strict access control, ensuring only authorized users can decrypt data based on predefined policies. Shared decryption mechanisms prevent unauthorized access to sensitive information. Chameleon hash functions verify data integrity, ensuring authenticity without compromising efficiency.Blockchain-based consensus mechanisms streamline transaction validation while incorporating incentives for security. This approach supports large datasets and numerous users, maintaining efficiency, encryption strength, and seamless scalability in cloud-based infrastructures. The study posed a central problem: how to attain scalable, secure, and decentralized multi-user audio communication in cloud-based environments without reliance on a single authority for key management. The results demonstrate that the integration of distributed key generation, CP-ABE with LSSS, and blockchain consensus significantly addresses this problem. The framework achieves minimal information loss, higher compression ratios, superior throughput, and reduced encryption time compared with state-of-the-art methods, thereby confirming the objectives outlined in the introduction.

However, the argument as a whole reveals certain boundaries. The reliance on AWS-based infrastructure introduces resource constraints that may not reflect performance in low-power IoT or edge computing environments. The dataset employed is limited to English audio, raising concerns about generalizability across multilingual datasets. Simulation assumptions about node honesty also pose potential threats to validity. Future research should therefore focus on testing the model in resource-constrained and heterogeneous network environments, expanding the dataset to multilingual corpora, and incorporating adversarial testing scenarios to evaluate robustness against malicious nodes. These directions will strengthen both the generalizability and resilience of the proposed approach.

The research was designed with specific objectives: (i) to design a decentralized key management framework that removes reliance on central authorities, (ii) to integrate CP-ABE with LSSS for fine-grained access control in multi-user settings, and (iii) to validate the framework on large-scale audio datasets in cloud-based environments. Each objective is directly reflected in the proposed design and confirmed through experimental evaluation.

The conclusion must explicitly articulate the degree to which these objectives have been fulfilled. The decentralized cryptographic framework effectively removes single points of failure, while CP-ABE and LSSS facilitate attribute-based secure access control. Furthermore, the experiments conducted on AWS validate enhanced throughput, decreased information loss, and reduced encryption time. These accomplishments affirm the research goals and illustrate the efficacy of the proposed system in tackling previously recognized challenges.

Despite the strong results obtained, certain limitations must be acknowledged. The framework has been validated in an AWS cloud environment with high computational resources, and similar performance may not be achieved in resource-constrained or edge devices. Scalability tests were limited to 100 concurrent transactions, and the behavior of the system under larger-scale deployment remains unverified. These limitations indicate the need for further testing in more diverse settings.Threats to validity also needs to be recognized. The TED-LIUM dataset, while suitable for evaluating audio communication frameworks, is biased toward English and may not fully represent multilingual environments. Simulation assumptions, including honest node participation, could differ from adversarial real-world conditions where malicious behavior is more likely. Identifying these threats provides transparency and indicates areas for future research expansion.

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