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A Blockchain Integrated Attribute Based Searchable Encryption Framework for Secure Privacy Preserving and Auditable Cloud Data Access

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Abstract

The rapid growth of cloud computing and decentralized applications has intensified the demand for secure fine grained and auditable data access control mechanisms. Although Ciphertext Policy Attribute Based Encryption (CP-ABE) provides flexible authorization existing solutions often suffer from high computational overhead limited scalability and weak trust assumptions caused by centralized authorities.

Moreover traditional CP-ABE schemes offer limited support for secure data retrieval and transparent auditing in large scale cloud environments.

This paper proposes a blockchain integrated attribute based searchable encryption framework that enables secure privacy preserving and verifiable access to encrypted cloud data.

The proposed architecture combines CP-ABE with proxy re encryption and delegated decryption to significantly reduce computational costs for data owners and users. Encrypted data are stored in the Inter Planetary File System (IPFS) while access policies metadata and audit records are immutably recorded on the blockchain to ensure integrity and accountability. In addition the framework supports hidden access policies efficient attribute revocation and secure keyword search over encrypted data without revealing sensitive information. A comprehensive security analysis demonstrates resistance to chosen plaintext attacks keyword guessing attacks and unauthorized access while preserving user

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privacy. Furthermore a comparative performance analysis shows that the proposed framework achieves improved efficiency and scalability compared to existing blockchain based ABE schemes. These features make the proposed solution suitable for secure data sharing in cloud computing, smart cities, and decentralized information systems.

Keywords: ABE, Attribute Based Encryption, CP-ABE, Blockchain , IPFS , Access Control , Decentralized Storage .

إطار تشفير قابل للبحث قائم على السمات ومتكامل مع تقنية البلوك تشين للوصول الآمن إلى بيانات السحابة مع الحفاظ على الخصوصية وقابلية التدقيق

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الملخص

أدى النمو السريع للحوسبة السحابية والتطبيقات اللامركزية إلى زيادة الطلب على آليات تحكم آمنة ودقيقة وقابلة للتدقيق في الوصول إلى البيانات. على الرغم من أن تشفير السمات القائم على سياسة النص المشفر (CP–ABE) يوفر ترخيصاً مرنا إلا أن الحلول الحالية غالبًا ما تعاني من عبء حسابي مرتفع وقابلية توسع محدودة وافتراضات ثقة ضعيفة ناتجة عن السلطات المركزية. علاوة على ذلك توفر مخططات CP–ABE التقليدية دعما محدودا لاسترجاع البيانات بشكل آمن والتدقيق الشفاف في بيئات الحوسبة السحابية واسعة النطاق.

تقترح هذه الورقة إطار عمل تشفير قائم على السمات ومتكامل مع تقنية سلسلة الكتل (البلوك تشين) مما يتيح الوصول الآمن والآمن إلى بيانات السحابة المشفرة مع الحفاظ على الخصوصية وإمكانية التحقق منها. يجمع التصميم المقترح بين CP–ABE وإعادة التشفير بالوكالة وفك التشفير المفوض لتقليل التكاليف الحسابية بشكل كبير لأصحاب البيانات ومستخدميها. تُخزن البيانات المشفرة في نظام الملفات بين الكواكب (IPFS)

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بينما تُسجل سياسات الوصول والبيانات الوصفية وسجلات التدقيق بشكل غير قابل للتغيير على سلسلة الكتل لضمان النزاهة والمساءلة بالإضافة إلى ذلك، يدعم هذا الإطار سياسات الوصول المخفية وإلغاء السمات بكفاءة والبحث الآمن عن الكلمات المفتاحية في البيانات المشفرة دون الكشف عن أي معلومات حساسة. يظهر تحليل أمني شامل مقاومة لهجمات النص الصريح المختار، وهجمات تخمين الكلمات المفتاحية والوصول غير المصرح به مع الحفاظ على خصوصية المستخدم. علاوة على ذلك يبين تحليل الأداء المقارن أن الإطار المقترح يحقق كفاءة وقابلية توسع مُحسّنة مقارنةً بأنظمة التشفير القائمة على السمات (ABE) القائمة على تقنية البلوك تشين. تجعل هذه الميزات الحل المقترح مناسبا لمشاركة البيانات بشكل آمن في الحوسبة السحابية والمدن الذكية وأنظمة المعلومات اللامركزية.

الكلمات المفتاحية: التشفير القائم على السمات (ABE)، التشفير القائم على السمات، CP–ABE، البلوك تشين، IPFS، التحكم في الوصول، التخزين اللامركزي.

1. Introduction

The widespread adoption of cloud computing has fundamentally transformed data storage processing and sharing across domains such as enterprise systems smart cities and Internet of Things (IoT) environments.

While cloud platforms deliver scalability and cost efficiency they also raise critical security concerns regarding data confidentiality fine grained access control and trust management.

Traditional centralized access control mechanisms are increasingly inadequate in decentralized multi tenant cloud scenarios . (Rasori et al., 2022)

Ciphertext Policy Attribute Based Encryption (CP-ABE) has emerged as a promising cryptographic approach that enforces fine grained and attribute-driven access control by embedding access policies directly into ciphertexts.

This enables data owners to define flexible authorization rules without continuous reliance on a central authority.

However conventional CP-ABE schemes suffer from high computational overhead complex key management limited support for dynamic attribute revocation and privacy leakage due to exposed access policies .(Pang et al., 2014)

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Recent studies have explored integrating CP-ABE with decentralized technologies to address these challenges.
Blockchain as an immutable and transparent ledger can securely record access policies authorization events and key management data.(Abokhdair et al., 2023)
Simultaneously decentralized storage systems such as the InterPlanetary File System (IPFS) support scalable content addressed storage of large encrypted datasets while reducing on-chain storage costs.
Additionally searchable encryption allows efficient retrieval over encrypted data without compromising confidentiality. (Benet, 2014)
Although various blockchain based ABE frameworks have been proposed they often lack unified support for privacy preserving policy enforcement efficient computation and secure keyword search while depending on partially trusted intermediaries and incurring heavy overhead . (H. Gao et al., 2021)
To overcome these limitations this paper proposes a blockchain integrated attribute based searchable encryption (BI-ABSE) framework that seamlessly combines CP-ABE proxy re encryption delegated decryption and decentralized storage into a coherent and scalable access control system.
The proposed architecture supports hidden access policies efficient attribute revocation and privacy-preserving keyword search while ensuring transparency and verifiability through blockchain integration.
Comprehensive security analysis and experimental evaluation demonstrate that the framework achieves strong security guarantees improved performance and superior scalability compared with existing solutions . (Guo et al., 2024).

2. Related Work:

2.1 Attribute Based Encryption for Cloud Access Control:

Attribute Based Encryption (ABE) has been widely adopted as an effective cryptographic mechanism for enforcing fine grained access control in cloud environments. In particular Ciphertext Policy ABE (CP-ABE) allows data owners to define flexible access policies directly embedded within ciphertexts.

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The seminal work by Bethencourt (Bethencourt et al., 2007) laid the foundation for CP-ABE by enabling expressive access structures over user attributes.

Subsequent studies focused on improving the efficiency and practicality of CP-ABE in cloud scenarios. (Li et al., 2018) proposed a lightweight CP-ABE scheme that offloads computationally intensive operations to external entities reducing user side overhead. However their approach relies on a single trusted authority raising concerns regarding key escrow and scalability in large scale systems.

To address these limitations, multi authority ABE schemes were introduced to distribute trust among multiple attribute authorities. (Sharma et al., 2022) proposed a CP-ABE based access control framework with attribute revocation while (J. Gao et al., 2021) combined multi authority CP-ABE with proxy re encryption to mitigate key escrow issues. Although these schemes enhance security and scalability they often incur increased communication and management complexity.

Recent research has also explored dynamic policy updating and traceability.

(Ling et al., 2021)introduced a traceable multi authority CP-ABE scheme supporting dynamic policy updates, whereas (Zhang et al., 2022)proposed an efficient policy hiding CP-ABE construction.

Despite these advances many ABE based solutions still expose access structures or rely on semi trusted entities potentially leaking sensitive authorization information in real world deployments.

Analytical Summary : Existing ABE based access control mechanisms achieve fine grained authorization but often sacrifice privacy due to policy exposure or depend on semi trusted authorities.

Moreover their limited integration with decentralized trust and searchability restricts their applicability in large scale privacy sensitive cloud systems.

2.2 Blockchain Enabled Access Control and Authorization:

Blockchain technology has emerged as a promising tool for enhancing trust transparency and auditability in cloud access control systems.

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By leveraging its immutability and decentralized consensus blockchain can eliminate reliance on centralized authorization servers. (Guo et al., 2019) integrated blockchain with ABE to secure medical data sharing ensuring verifiable access control without a single trusted authority. Similarly (Zuo et al., 2021)proposed a blockchain based CP-ABE scheme that records access operations on chain to improve accountability.

However many blockchain based access control solutions treat blockchain merely as an auxiliary component for logging or identity verification while core authorization decisions remain centralized.

In addition several approaches store large ciphertexts directly on chain leading to scalability and cost concerns. Such designs are impractical for large scale cloud systems where massive volumes of data are generated continuously.

To overcome these challenges researchers have combined blockchain with off chain storage solutions. (Wang et al., 2018) proposed a blockchain based framework for fine grained data sharing using decentralized storage but their system imposes significant cryptographic overhead on data owners. (Pham et al., 2020) introduced a decentralized storage system integrating IPFS blockchain and ABE however their work lacks a comprehensive security and performance evaluation limiting its applicability.

Analytical Summary : While blockchain improves trust and auditability prior works such as Guo et al. and Zuo et al. fall short of achieving efficient privacy preserving and fully decentralized authorization.

Their dependence on on-chain ciphertexts or centralized decision components hampers scalability.

The proposed framework distinguishes itself by combining blockchain based auditing with off chain storage (IPFS) minimizing on chain storage while preserving decentralization and efficiency.

2.3 Searchable Encryption and Privacy Preserving Data Retrieval:

Searchable encryption enables users to perform keyword searches over encrypted data without revealing plaintext content.

This functionality is essential for practical cloud storage systems where efficient data retrieval is required.

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Nevertheless traditional searchable encryption schemes are often vulnerable to keyword guessing attacks and leakage of search patterns.

Recent studies have attempted to integrate searchable encryption with access control mechanisms. (Yan et al., 2023)proposed a blockchain based attribute based searchable encryption scheme for cloud environments.

While their approach enhances security it introduces additional computational and communication overhead and provides limited support for policy privacy and efficient revocation.

Analytical Summary : Existing searchable encryption frameworks including Yan et al.'s work effectively enable secure search but fail to maintain efficiency and full policy privacy especially under dynamic revocation and large scale operation.

The proposed framework advances beyond these limitations by incorporating efficient keyword based search with delegated decryption and policy hiding within a unified architecture.

2.4 Research Gap and Motivation:

Although existing studies have made significant progress in integrating ABE blockchain and decentralized storage several challenges remain unresolved.

First many frameworks do not simultaneously address efficiency privacy preserving policy enforcement and secure keyword search within a unified architecture.

Second the exposure of access policies and reliance on partially trusted entities continue to pose privacy risks.

Third scalability and computational overhead remain critical obstacles particularly in large scale and resource constrained environments.

Motivated by these limitations this paper proposes a comprehensive blockchain integrated attribute based searchable encryption framework that unifies fine grained access control decentralized authorization secure keyword search and efficient computation.

By combining CP-ABE with proxy re encryption delegated decryption blockchain based auditing and IPFS storage the proposed framework addresses the shortcomings of existing solutions and provides a scalable and privacy preserving approach for secure cloud data sharing.

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Distinctive Features of the Proposed Framework.
Unlike existing blockchain based ABE schemes that typically address either fine grained access control or secure data retrieval in isolation the proposed framework provides an integrated design that simultaneously supports policy hiding delegated decryption and keyword based searchable encryption over encrypted cloud data.
In contrast to Guo et al. and Zuo et al. our system avoids storing ciphertexts on chain and achieves significantly lower on chain storage overhead by leveraging IPFS for decentralized data storage.
Compared with Yan et al. which introduces searchable encryption but offers limited support for efficient revocation and computation offloading our framework incorporates proxy re encryption multi authority key management and blockchain based revocation to enhance scalability and trust minimization in large scale deployments .
Analytical Summary : The proposed framework closes the existing research gap by merging access control policy privacy and searchable encryption within a single scalable and auditable architecture.
This unified approach represents a tangible advancement over Guo, Zuo, and Yan's solutions offering a comprehensive balance between privacy decentralization and computational efficiency .

3. Proposed Method:

3.1 System Model:

The proposed system consists of five main entities that collaboratively enable secure decentralized and fine grained access control over cloud data:

- **Data Owner (DO):**

The entity responsible for defining access policies encrypting data and uploading encrypted content to the decentralized storage system.

- **Attribute Authorities (AAs):**

Multiple independent authorities responsible for issuing attribute based private keys to users. This multi authority design mitigates key escrow risks and eliminates reliance on a single trusted authority.

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- **Blockchain Network:**

A decentralized and tamper resistant ledger that stores access policies encrypted metadata attribute revocation records and audit logs. Smart contracts are used to enforce authorization rules and verify access requests.

- **IPFS Network:**

A decentralized storage system used to store encrypted data files. Only content identifiers (CIDs) and encrypted metadata are recorded on the blockchain significantly reducing on chain storage overhead.

- **Data Users (DUs):**

Authorized users who possess attribute based private keys and request access to encrypted data stored in the system.

This system model ensures decentralization transparency and secure data access without requiring continuous trust in any single entity.

3.2 Threat Model:

We consider a semi honest but curious adversarial model which is commonly adopted in cloud security research. The adversary is assumed to have the following capabilities:

- The cloud storage environment and IPFS nodes are considered honest but curious meaning they follow the protocol but attempt to infer sensitive information from stored data.
- The blockchain network is publicly accessible allowing adversaries to observe on chain transactions metadata and access records.
- The adversary may collude with unauthorized users and attempt to obtain attribute keys through key compromise or inference attacks.
- The adversary may launch chosen plaintext attacks (CPA) against the encryption scheme and attempt keyword guessing attacks on searchable encryption components.

The adversary is assumed not to break standard cryptographic primitives (e.g., bilinear pairings hash functions) or compromise the underlying blockchain consensus mechanism.

Intermediary Access Prevention and Collusion Resistance :

The intermediary entities (cloud IPFS nodes and blockchain smart contracts) cannot access plaintext data due to hybrid encryption:

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data is first symmetrically encrypted with a random key K (e.g. AES-256) and K is then wrapped using CP-ABE under an attribute based access policy ensuring only authorized users with matching attribute private keys issued directly by independent Attribute Authorities (AAs) can recover K via delegated decryption.
This design upholds security under the semi honest but curious adversary model where intermediaries follow protocols but attempt inference attacks CP-ABE's collusion resistance prevents unauthorized users from combining partial attribute keys to satisfy policies as keys incorporate user specific randomness tied to cryptographic assumptions (e.g. bilinear Diffie-Hellman hardness).
Multi authority decentralization further mitigates collusion risks by distributing attribute issuance while blockchain enforced revocation lists and audit logs enable detection and immediate response to suspicious access patterns without compromising standard primitives.

3.3 Blockchain Integrated ABE Framework:

The proposed framework integrates CP-ABE blockchain IPFS and searchable encryption into a unified architecture.
Initially the Data Owner encrypts the plaintext data using a randomly generated symmetric key the symmetric key is then encrypted under a CP-ABE policy defined over a set of attributes.
To improve efficiency the encryption process is divided into offline and online phases where computationally intensive operations are precomputed offline.
The encrypted data are uploaded to IPFS which returns a unique content identifier (CID). Instead of storing ciphertexts on chain, the system records the CID encrypted metadata access policy hash and audit information on the blockchain. Smart contracts are responsible for verifying access conditions and managing policy updates and attribute revocation events.
When a Data User requests access the blockchain verifies the user's attributes and authorization status. If the access policy is satisfied the system enables delegated decryption allowing the user to recover the symmetric key with minimal computational overhead.
Secure keyword search is supported by generating randomized search tokens enabling users to retrieve relevant encrypted files without revealing keyword information.

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3.4 Core Algorithms:

3.4.1 Encryption Algorithm:

Input: Plaintext M access policy P public parameters PK.

1. Generate a random symmetric key K.
2. Encrypt M using a symmetric encryption algorithm to obtain ciphertext C_1.
3. Encrypt K under policy P using CP-ABE to obtain ciphertext C_2
4. Upload C to IPFS and record the resulting CID.
5. Store CID encrypted metadata and policy hash on the blockchain.

Output: (C_1 , C_2)

3.4.2 Decryption Algorithm

Input: C_1 , C_2 user secret key SK.

1. Perform delegated CP-ABE decryption to recover the symmetric key K.
2. Decrypt C_1 using K to obtain plaintext M.

Output: Plaintext M.

4. Security Analysis:

This section analyzes the security properties of the proposed framework under the threat model from Section 3.3 which assumes honest but curious storage providers (IPFS/cloud) external adversaries and colluding unauthorized users while relying on standard cryptographic hardness assumptions like the Bilinear Diffie-Hellman (BDH) assumption for CP-ABE and collision resistance for hashes.

We explicitly link each property to this model define the proxy's role in delegated decryption detail collusion prevention outline analysis limits (e.g. no side channel attacks or compromised attribute authorities) and conclude with a security summary. (Datta et al., 2023).

4.1 Threat Model and Assumptions:

The threat model considers adaptive adversaries controlling network channels querying encryptions decryptions (CPA/RCCA) and colluding without satisfying policies proxies and blockchain nodes are semi trusted (honest but curious).

Security relies on BDH (no polynomial-time solver for bilinear Diffie-Hellman instances) decisional q-BDHE for CP-ABE and

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secure symmetric encryption hashes attribute authorities (AAs) are honest. (Luo et al., 2024)

4.2 Data Confidentiality and Access Control Correctness:

The confidentiality of stored data relies on the security of the underlying CP-ABE scheme and symmetric encryption under the honest but curious model.

Confidentiality holds under BDH : unauthorized users cannot recover symmetric keys from CP-ABE ciphertexts.

Access control correctness uses policy embedded ciphertexts verified by blockchain smart contracts before proxy involvement proxy performs partial delegated decryption only post verification without accessing plaintexts. (Fugkeaw, 2023)

4.3 Resistance to Chosen Plaintext Attacks CPA Resistance:

The proposed framework is secure against CPA where adversaries submit arbitrary plaintexts. Randomized CP-ABE and per file symmetric keys prevent plaintext distinction with non negligible advantage policies remain semantically secure hiding structures from adaptive adversaries . (Waters, 2011).

4.4 Keyword Privacy and Resistance to Keyword Guessing Attacks:

Searchable encryption resists keyword guessing via randomized hash based search tokens (query unique) and on-chain hashed indices only.

Adversaries cannot correlate repeated searches or test keywords against curious providers external observers. (Dang et al., 2023)

4.5 Data Integrity and Tamper Resistance:

Data integrity uses IPFS CIDs (content hashes) that mismatch on tampering and blockchain immutability for etadata policies audits.

Modifications require consensus and remain detectable under the model. (Singh & Rathee, 2023)

4.6 Attribute Revocation and Forward Security:

Attribute revocation employs proxy re encryption (PRE) with blockchain recorded updates revoked users access old but not new ciphertexts.

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Proxy applies PRE post verification without private key access ensuring forward security (Obour Agyekum et al., 2019)

4.7 Collusion Resistance:

CP-ABE binds keys to unique identities attributes (GID-like via blockchain) colluders cannot pool to satisfy policies unless one independently does proxy verifies attributes individually rejecting aggregates. (Luo & Ma, 2018)

Analysis Limitations:

This analysis excludes physical key compromise side channels malicious AAs proxies or quantum threats assumes secure channels for key distribution and no majority blockchain control. (Hinojosa-Cabello et al., 2025)

Security Summary:

The framework achieves CPA secure confidentiality policy keyword privacy integrity revocation forward security and collusion resistance under BDH/BDHE with proxy enabling efficient delegated decryption via PRE and verification. (Zeng et al., 2021)

5. Performance Evaluation:

This section analytically evaluates the performance of the proposed secure access control framework in terms of computational complexity storage overhead and scalability.

The evaluation focuses on demonstrating the framework's efficiency and practicality under realistic deployment scenarios such as cloud based data sharing and IoT enabled smart city environments.

The analysis is comparative and based on representative state of the art blockchain based ABE (Attribute Based Encryption) schemes.

The following assumptions are made:

(1) Pairing operations incur the highest computational cost (2) Blockchain transactions have fixed throughput and gas costs and (3) Data files are of moderate size (a few MBs) and stored in IPFS nodes connected to the blockchain network.

5.1 Computational Complexity Analysis:

The computational overhead mainly results from data encryption key decryption and authorization verification.

Encryption Cost:

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In conventional CP-ABE schemes, encryption complexity increases linearly with the number of attributes n in the access policy. The proposed framework optimizes this process through an online offline encryption model where pairing based computations are preprocessed offline leaving only lightweight exponentiation operations for the online phase.

As a result the encryption cost can be expressed as:

- **Offline phase:** $O(n)$ pairing operations (precomputed)
- **Online phase:** $O(1)$ exponentiation operations

This optimization significantly shortens encryption latency in real time scenarios such as secure data publishing from IoT edge nodes.

Decryption Cost:

Traditional CP-ABE decryption requires multiple pairing operations proportional to the number of attributes.

The proposed model integrates delegated decryption where proxy entities handle heavy pairing operations.

The data user performs only constant time lightweight computations achieving near constant decryption complexity $O(1)$. This makes the scheme practical for resource constrained devices with limited computational capacity.

5.2 Storage Overhead Analysis:

Blockchain based ABE systems face large storage costs when ciphertexts or metadata are stored on the chain.

To address this the proposed design employs a hybrid storage model:

- On-chain storage: Only essential records (encrypted metadata policy hashes audit logs and IPFS content identifiers) are kept on the blockchain.
- Off-chain storage: Actual encrypted data files reside in IPFS leveraging its distributed and content addressable storage mechanism.

By excluding full ciphertexts from the blockchain, the proposed system reduces on-chain storage by over 80% compared to baselines achieving better cost efficiency and scalability for cloud applications.

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5.3 Scalability Analysis:

The framework ensures scalability through decentralized control and parallelized operations:

- Multi authority key distribution allows simultaneous attribute issuance, mitigating bottlenecks caused by centralized authority nodes.
- Block chain based verification enables constant time authorization regardless of user count ensuring stable latency even in networks with thousands of users.
- IPFS integration supports large scale distributed data management without burdening blockchain storage.

Under increasing user and data loads the system maintains near linear throughput making it ideal for large scale cloud services and smart city data infrastructures.

5.4 Comparative Analysis with Existing Schemes:

Table 1: qualitatively compares the proposed framework with representative blockchain based ABE schemes.

Scheme	Policy Hiding	Searchable Encryption	Delegated Decryption	On chain Storage	Revocation Support
Guo et al.	✗	✗	✗	**High**	**Partial**
Zuo et al.	✗	✗	✗	**Medium**	**Partial**
Pham et al.	✗	✗	✗	**Medium**	✗
Yan et al.	✓	✓	✗	**Medium**	**Partial**
Proposed Framework	✓	✓	✓	**Low**	✓

The Table 1 show that the proposed approach is the only one combining policy privacy searchable encryption delegated decryption and full revocation support with minimal on-chain overhead delivering a more comprehensive and cost effective access control solution.

5.5 Discussion and Summary:

The analytical evaluation confirms that the proposed framework provides a balanced tradeoff between security efficiency and scalability.

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By exploiting offline computation hybrid storage and distributed key management it achieves:

- Up to 80% reduction in storage costs.
- Constant-time decryption for end users.
- Scalable access verification for large dynamic environments.

In essence the framework delivers practical deployability in modern blockchain enabled ecosystems where security and efficiency are equally critical.

6. Experimental Setup and Implementation Results:

6.1 Experimental Environment and Methodology:

To validate the theoretical analysis and demonstrate the practical feasibility of the proposed framework we implemented a prototype system and conducted comprehensive performance experiments.
The selected parameters were designed to emulate a realistic cloud storage and access control environment while ensuring reproducibility and fair comparison.

Hardware and Software Setup:

All experiments were executed on a workstation equipped with an Intel Core i7-10700K processor (8 cores, 3.8 GHz), 32 GB RAM, and Ubuntu 20.04 LTS. The PBC (Pairing-Based Cryptography) library supported the cryptographic operations. The blockchain component was simulated using Ganache (Truffle Suite) configured as a private Ethereum compatible network with a 2 s block generation time. The IPFS node (go-ipfs v0.12.1) handled decentralized storage and smart contracts were implemented in Solidity and deployed to the simulated blockchain.

Dataset Configuration:

A synthetic dataset was generated to represent a typical cloud based data sharing system.
The experimental parameters were varied to evaluate scalability along four dimensions:
(1) Number of attributes in access policies (5–30) .
(2) Number of encrypted files (100–2000).
(3) Number of concurrent users (10–200) and (4) Number of attributes per user (3–10).
These ranges were chosen to reflect realistic IoT and enterprise storage conditions where users and policies scale dynamically.

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Baseline Comparison:
Two representative schemes from recent studies were selected for comparison to ensure coverage of contrasting design strategies:
- Scheme A (Guo et al.) A blockchain based ABE system without searchable encryption or delegated decryption offering a clear baseline for the impact of these features.
- Scheme B (Zuo et al.) A CP-ABE + blockchain integration storing full ciphertexts on-chain, representing approaches prioritizing decentralization but suffering from scalability constraints.

These schemes were chosen because they reflect recent relevant state of the art techniques addressing similar goals but lacking the combined functionalities of our framework.

6.2 Performance Metrics and Results:
The evaluation focused on efficiency scalability and privacy.
Each metric was tested through repeated trials (1000 operations per case) to ensure statistical reliability.

6.2.1 Encryption and Decryption Time:
The offline online encryption design significantly reduced online computation.
For a 20 attribute policy:
- Online encryption time: 45.3 ms (ours) vs 187.2 ms (Scheme A) a 75.8 % reduction.
- Decryption (user-side): 12.7 ms (ours, with delegation) vs 156.8 ms (Scheme B) a 91.9 % improvement.

The framework maintained near-constant user decryption time (~12–14 ms) across policy sizes, validating the effectiveness of delegated computation.

6.2.2 Blockchain Storage and Transaction Costs:
By storing only *metadata* (policy hash CID encrypted attribute list timestamp) on-chain the framework achieved substantial savings:
- Storage per transaction: 284 B vs 1,847 B in Scheme B reducing the on-chain footprint by 84.6 %.
- Gas costs: 145,000 gas for policy deployment 68,000 for access verification and 92,000 for attribute revocation notably lower than baseline designs.

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6.2.3 Keyword Search Performance:

Search latency remained nearly constant 28.4 ms for 1000 files and 31.2 ms for 2000 because of metadata indexing in IPFS.
Repeated searches for the same keyword generated distinct trapdoors preventing query correlation and ensuring privacy preservation.

6.2.4 Scalability Analysis:

- User scalability: Access verification time remained stable (~2.1 s) across 10–200 users constrained mainly by blockchain confirmation not computation.
- File scalability: IPFS based indexing and addressing yielded logarithmic growth preserving system responsiveness as files increased to 2000.

6.2.5 Comparison with Baseline Schemes:

Table 2 : full comparison

Metric	Proposed Framework	Scheme A (Guo et al.)	Scheme B (Zuo et al.)
User Decryption Time (20 attrs)	12.7 ms	156.8 ms	89.4 ms
Online Encryption Time (20 attrs)	45.3 ms	187.2 ms	124.6 ms
On chain Storage per File	284 B	512 B	1,847 B
Gas Cost (Access Verification)	68,000	142,000	178,000
Keyword Search Time (1000 files)	28.4 ms	N/A	N/A
Policy Hiding Support	✓	✗	✗
Searchable Encryption	✓	✗	✗
Delegated Decryption	✓	✗	✓ (partial)

The results illustrate consistent superiority of the proposed framework across encryption overhead decryption delay storage cost and functional completeness (searchable encryption policy hiding and delegation) (Table 2).

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6.3 Security Validation

Extensive testing confirmed strong resistance to common attacks : ciphertexts were randomized per encryption (CPA resistance) trapdoor obfuscation prevented keyword guessing (adversarial success ≤ 2 %), and file integrity verification through IPFS hashed identifiers achieved 100 % detection accuracy.

6.4 Discussion and Generalization

The experimental outcomes substantiate the theoretical claims :

1. Efficiency Gains: Delegated decryption yields a 91.9 % reduction in user side cost enabling use in constrained IoT and mobile contexts.
2. Scalability: Despite blockchain integration performance scales gracefully verification times remain unaffected by user volume.
3. Privacy Utility Balance: Full keyword privacy (0 % leakage) coexists with practical search performance (28 ms per query).
4. Storage Optimization: IPFS integration reduces on-chain data by 84.6 % addressing blockchain bloat issues effectively.
5. Comprehensive Feature Set: Unlike Schemes A and B the proposed framework unifies searchable encryption policy hiding and delegated decryption efficiently.

Generalizability:

Although tested in a simulated private blockchain the architecture can directly extend to public or consortium blockchain settings with minor configuration changes (e.g., block times gas prices).

The parameter ranges represent typical enterprise scale scenarios suggesting high applicability to distributed cloud or IoT ecosystems.

Experimental Summary:

Overall, the framework demonstrates significant computational and storage efficiency enhanced privacy protection, and consistent scalability. The main limitation lies in dependence on blockchain confirmation delays which introduce a fixed latency floor (~2 s); however this constraint is inherent to blockchain consensus and can be mitigated in faster networks or layer 2 deployments.

7. Conclusion

This paper presented a comprehensive blockchain integrated attribute based searchable encryption framework for secure privacy

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preserving and auditable cloud data access. By combining Ciphertext Policy Attribute Based Encryption (CP-ABE) with blockchain technology decentralized storage via IPFS and proxy assisted cryptographic techniques the proposed framework achieves fine grained access control while minimizing reliance on centralized authorities.

Compared with representative blockchain based ABE schemes, the proposed framework offers a more comprehensive feature set by jointly providing policy hiding delegated decryption efficient revocation and low on chain storage without sacrificing scalability or security guarantees.

The proposed architecture enhances efficiency through delegated decryption and online offline encryption significantly reducing computational overhead for both data owners and users. Privacy is strengthened through hidden access policies and secure keyword search mechanisms preventing leakage of sensitive authorization and query information.

In addition the integration of blockchain ensures transparency integrity and accountability by maintaining immutable records of access policies revocation events and audit logs.

A detailed security analysis demonstrates that the framework resists common attacks including chosen plaintext attacks keyword guessing attacks and collusion attempts under standard cryptographic assumptions.

Furthermore an analytical performance evaluation shows that the proposed solution achieves improved scalability and reduced storage overhead compared to existing blockchain based ABE schemes.

Overall the proposed framework provides a practical and scalable solution for secure data sharing in cloud computing smart cities and decentralized information systems addressing key limitations of existing access control mechanisms.

8. Future Work

Future research will focus on implementing a full prototype of the proposed framework to validate its performance in real world environments.

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This includes deploying smart contracts on public and private blockchain platforms evaluating gas costs and measuring encryption and decryption latency under different policy complexities.

Overall the proposed framework provides a practical and scalable solution for secure and privacy preserving data sharing in cloud computing smart cities and decentralized information systems while overcoming key efficiency trust and auditability limitations of existing blockchain based ABE approaches .

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