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CONTENTS

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OBJECTIVES

HYPOTHESIS (ES)

RESEARCH METHODOLOGY

RESULTS & DISCUSSION

FINDINGS

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SECURE DATA MANAGEMENT MODEL (SDMM): ACCESS POLICY HIDING FOR EFFICIENT SHARING AND REVOCATION USING BLOCKCHAIN

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ABSTRACT

In today's context, the secure sharing of sensitive data is paramount for maintaining privacy and confidentiality. Additionally, efficient revocation mechanisms play a vital role in promptly revoking access privileges to prevent unauthorized usage. Our work addresses these concerns by leveraging blockchain technology to share Attribute-Based Encrypted (ABE) ciphertext, which includes an IPFS file URL, access policies, and a revocation list. By incorporating a tree-based revocation mechanism and integrating Attribute-Based Access Control (ABAC) through smart contracts, such as OAMC, SAMC, ACC, and RMC, we ensure the seamless execution of necessary operations. Our system not only protects access policies but also enhances the efficiency of the revocation mechanism. Through extensive experimental evaluation and analysis, we have demonstrated the better performance of our methods compared to existing approaches.

KEYWORDS

ABE, ABAC, tree, revocation, IPFS, Blockchain.

JEL CODES

D82, D85, L86.

1. INTRODUCTION

To ensure the protection of sensitive information and maintain privacy, secure data sharing is crucial. It prevents unauthorized access and safeguards data from potential breaches. Additionally, efficient revocation mechanisms are necessary to promptly revoke access privileges, preventing unauthorized usage and maintaining control over shared data, thereby enhancing overall data security. These objectives can be achieved by leveraging attribute-based mechanisms such as Attribute-Based Encryption (ABE) and Attribute-Based Access Control (ABAC), in combination with blockchain technology, which adds an extra layer of transparency and immutability to the sharing and revocation processes.

Blockchain operates through the integration of cryptographic principles, decentralized architecture, and distributed consensus. Transactions are organized into blocks and connected using cryptographic hashes, forming an unchangeable data chain. Once a block is added, it becomes nearly impossible to alter, ensuring transparency, security, and trust in the system. Consensus algorithms like Proof of Work or Proof of Stake validate and establish agreement among participants on the blockchain's state. The immutability of added blocks ensures transparency, security, and a trustworthy system.

Attribute-Based Encryption (ABE) is a cryptographic method that facilitates access control by leveraging attributes. It enables the encryption of data with specific attributes, ensuring that only users possessing corresponding attributes can decrypt and access the information. ABE empowers fine-grained access control, offering flexibility and customization in the secure sharing of encrypted data.

Attribute-Based Access Control (ABAC) is a security framework that governs access to resources based on associated attributes of users, objects, and the environment. ABAC enables detailed control by considering multiple attributes concurrently, resulting in accurate and context-aware access decisions. This model offers a fine-grained level of access control, ensuring that resources are only accessible to authorized entities based on their attribute values.

In the realm of access control and data protection, ABE (Attribute-Based Encryption) and ABAC (Attribute-Based Access Control) are interconnected yet separate concepts. ABE primarily deals with encryption and decryption, ensuring secure data storage and sharing. In contrast, ABAC functions as an access control model, making access decisions based on various attributes associated with resources.

In this paper, we have used both ABE, ABAC mechanisms on blockchain along with offline storage IPFS and proposed a model to realize efficient sharing and revoking mechanisms. This paper makes three distinct contributions, which are outlined as follows:

- Outsourced storage for data owner in IPFS
- Auxiliary tree-based revocation
- Using blockchain to maintain and store cipher text that contains encrypted IPFS URL data along with both revocation list and access policies
- Access control decisions are based on smart contracts
- Providing forward and backward security with only revocation list update
- Existing Cipher text is not actually updated in blockchain, but copy of cipher text is fetched, modified and updated. The updated cipher text copy is always place in blockchain as new transaction for every revoked use

The rest of the paper is structured as follows in the subsequent sections: The section II of this paper explores into an examination of previous studies and related work. Section III describes the proposed Model, providing a in detail explanation. In Section IV, a detailed analysis of the results is presented and discussed. Moving forward, Section V provides insights into future scope and pivotal research directions. Finally, Section VI concludes by summarizing the key findings and implications of our research work.

2. OBJECTIVES OF THE STUDY

1. To protect access policies from infringement.
2. To provide effective revoke mechanisms.
3. For Providing flexible data sharing.

3. RESEARCH METHODOLOGY OF THE STUDY

Systematic approach and techniques are applied to conduct the research and data is collected through different primary and secondary sources.

4. RELATED WORK

This section will focus on most recent research works investigated on the concepts of ABE (Attribute-Based Encryption), ABAC (Attribute-Based Access Control) and blockchain for secure and trustworthy data sharing. Additionally, the section will concentrate on techniques employed for hiding access policies along with various revoking mechanisms employed until now.

The ReLAC method [1] applies the CP-ABE (Ciphertext-Policy Attribute-Based Encryption) mechanism along with an auxiliary binary tree for user revocation. Access policies and revocation are stored as part of the ciphertext. However, to ensure forward and backward security, the ReLAC scheme incurs a high overhead due to the need for cipher text updates and key generation for each revoked user.

The authors in [2] implemented attribute revocation, which indirectly revokes users. However, the overhead of updating secret keys is greater than that of updating the ciphertext.

In [3], the attribute manager was utilized to address the challenge of attribute revocation in the system. However, the scheme incurred additional computation overhead as it required updating the keys and ciphertext of unrevoked users when revoking a malicious user.

During the update phase described by [4], only a single component of the ciphertext related to the user tree was modified. This approach decrease the computational overhead; however, it also resulted in a reduction in the scheme's security.

The CP-ABE scheme proposed by [5] utilizes a binary tree associated with user formation for implementing attribute revocation and user tracing. This scheme has shown to be effective in ensuring security against chosen plaintext attacks and selective access policy scenarios.

In their work, Yang et al. [6] presented a data sharing mechanism that combines blockchain and edge computing to support attribute revocation. However, the scheme mandates the attribute authority to update the attribute key for users who possess the revoked attribute. Additionally, fog nodes are responsible for carrying out ciphertext updates.

Wan et al. [7] proposed a variant of Attribute-Based Encryption (ABE) with user revocation in the random oracle model. However, this approach requires an additional attribute to record expiration time and necessitates re-encryption to uphold data confidentiality against revoked users. As a result, the scheme incurs linear revocation complexity, as the key generation center must distribute updated secret keys to non-revoked users during each revocation epoch.

In their study, Yeh et al. [8] utilized standard Attribute-Based Encryption (ABE) along with a Merkle hash tree to implement user revocation while considering data confidentiality against revoked users. However, they employed a ciphertext re-encryption approach to safeguard data confidentiality, which resulted in a substantial overhead for data owners who needed to re-encrypt their data in each revocation epoch.

In their work, Hoang et al. [9] developed a forward-secure access control mechanism that incorporates attribute revocation. However, in addition to the intricate ciphertext update operations, the scheme also necessitates updating the non-revoked proof and decryption keys for existing users who possess the revoked attribute.

To safeguard users' sensitive information, researchers have explored policy hiding CP-ABE schemes. Nishide et al. [10] introduced the first partially policy hiding CP-ABE scheme, utilizing AND gates and achieving security in the selective model. Lai et al. [11] supported LSSS (Linear Secret Sharing Scheme) policies, achieving full security, although it did not support a large universe. Lewko et al. [12] proposed a CP-ABE scheme, demonstrating its security based on the dual system encryption method [13].

Okamoto et al. [14] successfully developed a scheme that achieves full security. Cui et al. [15] introduced a policy hiding CP-ABE scheme supporting LSSS policies and a large universe, although it only achieves security in the random oracle model. Han et al. [16] proposed a partially policy hiding CP-ABE scheme based on prime order groups, but it relies on a trusted central authority for secret key distribution.

Wang et al. [17] presented a scheme that provided support for revocation and policy hiding but did not accommodate LSSS policies. Moreover, none of the previously mentioned schemes supported outsourced decryption. In contrast, Zhong et al. [18] proposed a CP-ABE scheme that supported outsourced decryption. However, it lacked correctness verification for outsourced results and fell short in protecting user privacy.

In contrast to the pros and cons of the recent works on policy hiding and revocation mechanisms discussed earlier, our proposed method outperforms these existing methods by offering improved performance with reduced computational overhead. Furthermore, our approach includes a blockchain-based access control system, which serves as an additional feature to enhance trust, privacy, and transparency, setting it apart from the aforementioned methods.

5. PROPOSED SECURE DATA MANAGEMENT MODEL (SDMM)

The proposed secure data management model mainly contains three modules:

5.1 Initial setup Module

In this module data owner is going to store his file in decentralized storage IPFS. This module has following steps

- Data owner(O) stores his file in IPFS and will get URL
- Data owner(O) encrypts that URL using CP-ABE
- Encrypted fixed cipher text is associated with updatable access policies written by owner(O) along with updatable empty revocation list
- Now the resulted cipher text is stored in blockchain
- Data owner then deploy four access control smart contracts OAMC (Object Attribute Management Contract), SAMC (Subject Attribute Management Contract), ACC (Access control contract), RMC (revocation Management Contract) to control the access

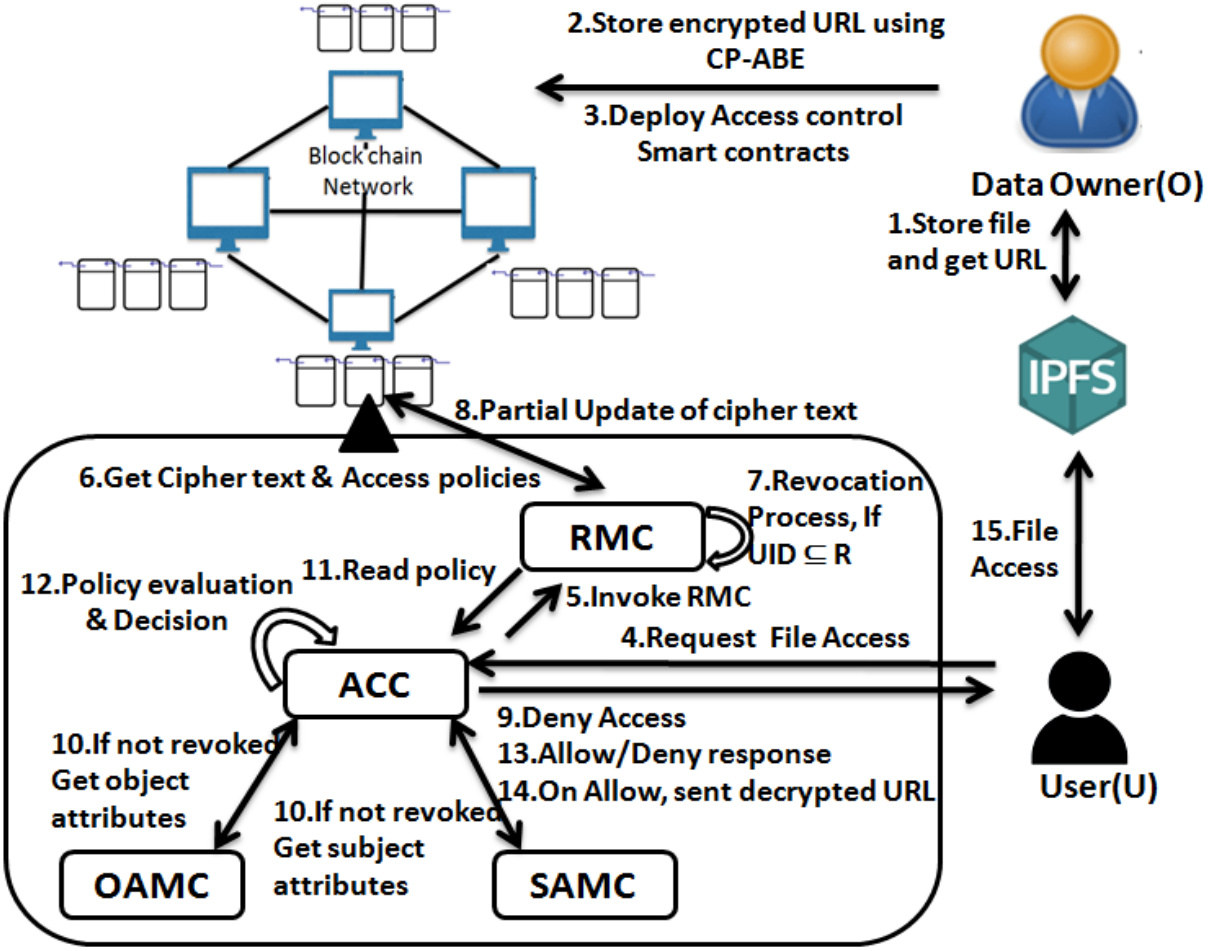
Here OAMC is used to manage attributes related to the object, SAMC is used to manage attributes related to subject, ACC receive requests from user and then it is going to act as PDP (Policy Decision Point) and PEP (Policy Enforcement Point) to make final decisions regarding access, RMC is used to control entire revocation process and also modify updatable components of cipher text such as revocation list and access policies.

5.2 Revocation Module

This module represents the logic that represents sharing and access related aspects. This module has the following steps

- User (U) uses the WebApp and send access request to file Owner (O).
- This request is received by PEP smart contract ACC
- Now PEP forward received access request to PDP which is part of ACC.
- As a Policy Decision Point (PDP), ACC initially invoke RMC.
- Now Revocation Management Contract (RMC) read revocation list(R) and access policies (P) associated with cipher text (CT).
- Now RMC checks whether the user (U) is present in revocation list or not. i.e., if UID $\subseteq$ R
- If user present in revocation list(R), then access request is rejected.
- Otherwise, ACC calls OAMC, SAMC to get object and subject attributes and use access policies (P) to make final access decision.
- If user attributes match access policies(P), then PDP announces decision “Allow” and user(U) is given response with the cipher text that contains URL of file present in IPFS.

FIG. 1: ARCHITECTURE OF SECURE DATA MANAGEMENT MODEL



5.3 Data Sharing Module

This module is used by the file owner (O) to revoke access from User(U). This module has the following steps:

- To revoke access from user(U), data owner sends revocation request along with user id (UID) to ACC.
- This request is received by PEP (Policy Enforcement Point) component of ACC.
- Now ACC invoke RMC (Revocation Management Contract)
- The RMC component invoke the initTree() and updateTree() methods
- Initially initTree() method is invoked to build auxiliary binary Tree(T) out of revocation list(R).
- This binary tree represents all the users who are currently having access to the cipher text of IPFS URL. In this binary tree all the users are represented as leaf nodes.
- After tree initialization, RMC calls updateTree() method to check whether the revocation list(R) contains the UID of the user. Here special algorithms like Cover(R) and Path(i) are used to complete the operation
- If UID $\not\subset$ R, then UID of user is added to revocation list(R) and binary tree is updated to complete revocation process
- Updating revocation list of cipher text represent partial updating, where actual IPFS URL cipher data is fixed
- Now the updated revocation list(R) is updated in the its part of cipher text (CT)
- A special transaction is required to write the updated ciphertext to the blockchain. This is due to the immutable nature of the blockchain, which means that once data is recorded on the blockchain, it cannot be modified or deleted. Therefore, in order to update the ciphertext, a new transaction needs to be created, which includes the revised ciphertext and any associated changes.

The overall architecture that contains aforementioned three models are represented in Fig. 1.

6. EXPERIMENTAL SETUP AND RESULT ANALYSIS

Our model was tested by setting up a local Ethereum blockchain using the Rinkeby testnet. For experimentation purposes, we established this network with ten basic blockchain nodes. The system used for these experiments is equipped with an i5 processor and 16GB of RAM. This configuration ensured that our model could run smoothly and efficiently during testing and evaluation.

We utilized the Ganache software to access the local blockchain network and installed IPFS for decentralized storage. Additionally, we designed a user-friendly WebApp using AngularJS to serve as an interface between users and the blockchain network.

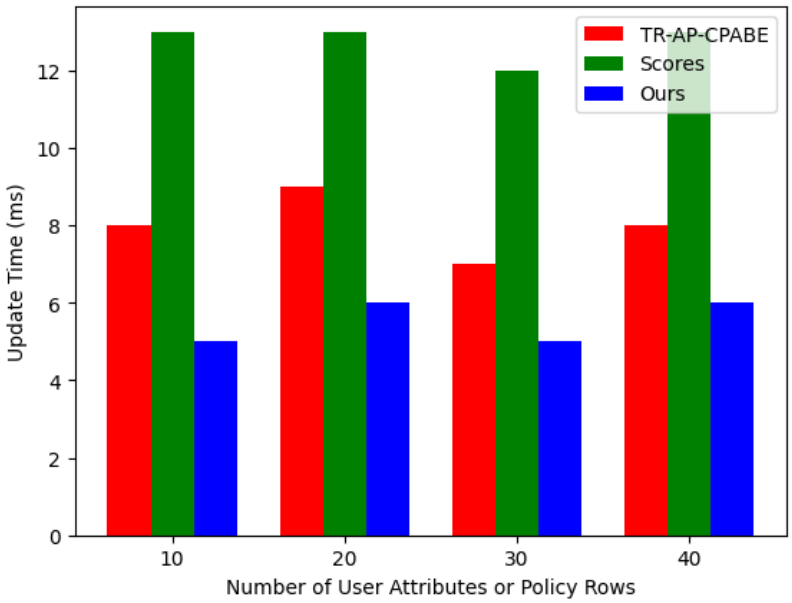
To enable interaction between the WebApp and the blockchain network, we integrated Web3JS within our WebApp, which allows us to communicate with the Metamask extension. Metamask, in turn, facilitates the interaction between our WebApp and the local Ganache blockchain network.

Our secure data management model has been primarily compared to two closely related models, namely the TR-AP-CPABE model [4] and the ReLAC model [1].

6.1 COMPARISON 1: ***Ciphertext updating Time Analysis***

A comparison was conducted among the aforementioned three models regarding the update time of ciphertext, using the metrics of "Number of attributes" and "Update Time." Our model exhibited better performance in this comparison. This is attributed to the fact that our model does not update the existing ciphertext directly in the blockchain. Instead, a modified copy of the ciphertext is created and written into the blockchain as a new transaction.

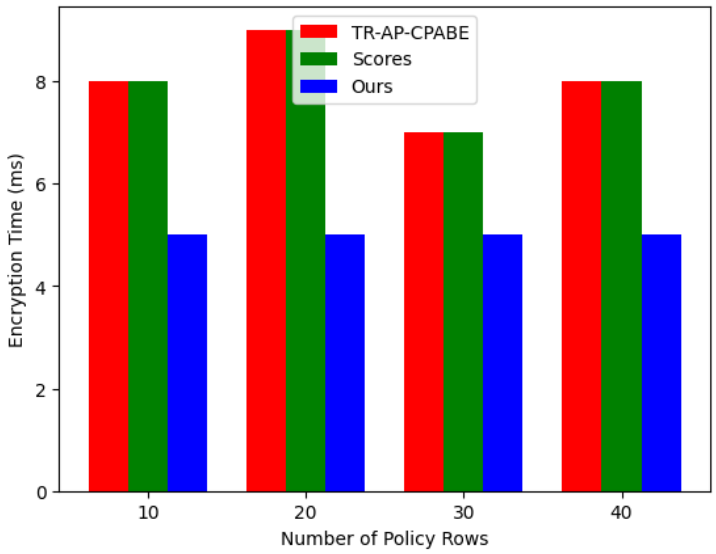
FIG. 2: UPDATE TIME ANALYSIS



6.2 COMPARISON 2: *Encrypt Time Analysis*

In contrast to the TR-AP-CPABE model [4] and the ReLAC model [1], our approach differs in how we handle file encryption. Instead of encrypting the entire file to obtain ciphertext, we store the actual file in IPFS and generate a file URL. This file URL is then encrypted and stored in the blockchain. This approach significantly reduces the time required for encryption compared to the existing models.

FIG. 3: ENCRYPTION TIME ANALYSIS



6.3 COMPARISON 3: *Others*

Our model, implemented in blockchain-based Attribute-Based Access Control (ABAC) with Attribute-Based Encryption (ABE), offers improved trust, privacy, non-repudiation, and decentralization compared to the TR-AP-CPABE model [4] and the ReLAC model [1].

7. FUTURE SCOPE AND RESEARCH DIRECTIONS

Neither the TR-AP-CPABE model [4] nor the ReLAC model [1], including our Secure Data Management Model (SDMM), currently support dynamic access control with temporal dimension and multi-granularity. However, our future goal is to expand our model to encompass both dynamic temporal access control and multi-granularity, incorporating efficient mechanisms for these capabilities.

8. CONCLUSION

In conclusion, our work presents a comprehensive solution for secure sharing of sensitive data by leveraging blockchain technology. We have successfully incorporated Attribute-Based Encrypted (ABE) ciphertext, IPFS file URLs, access policies, and a revocation list within the blockchain framework. By integrating a tree-based revocation mechanism and utilizing Attribute-Based Access Control (ABAC) through smart contracts, such as OAMC, SAMC, ACC, and RMC, we ensure the efficient and seamless execution of necessary operations.

Our system not only secures access policies but also enhances the overall efficiency of the revocation mechanism, enabling effective revocation of access privileges to stop unauthorized usage. Through extensive experimental evaluation and analysis, we have demonstrated the performance of our SDMM when compared to existing approaches.

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