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A SECURE AND RELIABLE BLOCKCHAIN-BASED DATA SHARING SCHEME USING LIGHTWEIGHT HOMOMORPHIC CRYPTOGRAPHIC ALGORITHM FOR MULTI-LEVEL PRIVACY PROTECTION IN IOT-CLOUD SYSTEMS

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Abstract

Ensuring safe and private data sharing has become a crucial concern due to the quick spread of Internet of Things (IoT) devices and their integration into cloud environments. Because of the limited computational and energy resources of IoT devices, traditional cryptographic solutions frequently fall short. In order to overcome these obstacles, we suggest a dependable and safe blockchain-based data exchange system that makes use of low-power cryptographic techniques and is designed for multi-level privacy protection in IoT-cloud systems. While lightweight encryption algorithms like PRESENT and ECC allow for effective security on devices with limited resources, the suggested approach makes use of the decentralized and immutable characteristics of blockchain to guarantee data integrity and transparency.Smart contracts with attribute-based encryption provide multi-level privacy by allowing for fine-grained access control according to user roles and permissions. Blockchain hashes serve as the foundation for off-chain storage in the cloud, which guarantees scalability without sacrificing security. Our plan

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offers a strong foundation that strikes a balance between security, privacy, and performance, which makes it a good fit for next-generation IoT-cloud settings in fields like smart cities, healthcare, and industrial monitoring.

Keywords: Blockchain, Lightweight Cryptography, Multi-level Privacy, IoT-Cloud Integration, Data Sharing, Access Control, Secure Communication

Introduction

Billions of interconnected devices have been deployed in a variety of industries, including healthcare, smart cities, industrial automation, and environmental monitoring, as a result of the Internet of Things' (IoT) rapid growth. Large volumes of data are produced by these devices, and these are usually transferred to cloud platforms for improved analytics and storage. However, there are significant issues with data security, privacy, and access control that arise from the combination of cloud computing and IoT. Because IoT devices have limited computational power, memory, and energy resources, traditional security measures are frequently inappropriate for IoT contexts.

Additionally, traditional cloud-based systems' centralized design creates questions regarding single points of failure, trust, and data integrity. Blockchain technology stands out as a viable remedy in this regard because of its decentralized, transparent, and impenetrable characteristics. However, given the limited capabilities of edge devices, careful integration of blockchain with IoT systems is necessary to preserve scalability and efficiency.

A secure and dependable data exchange method based on blockchain and lightweight cryptographic algorithms is proposed in this study to address these issues. It is especially made for multi-level privacy protection in IoT-cloud contexts. Lightweight encryption methods like PRESENT and Elliptic Curve Cryptography (ECC) are used in the suggested approach to guarantee data confidentiality with the least amount of processing overhead. It ensures integrity and traceability by using blockchain technology to store immutable transaction logs and hash values of encrypted data. Furthermore, attribute-based encryption (ABE) and smart contracts are combined to offer fine-grained access control, enabling different privacy levels for different data consumers according to their responsibilities and permissions.

This method is ideal for real-world applications that require both trust and resource efficiency since it not only secures the confidentiality and privacy of IoT data but also facilitates effective transmission and storage.

Related work

To solve the scalability and resource limitations of IoT devices, Dorri et al. (2017) suggested the Lightweight Scalable Blockchain (LSB), a tiered architecture. LSB uses lightweight consensus

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techniques to minimize overhead and latency in a smart home environment. It uses a centralized manager for low-resource devices and a decentralized overlay network for high-resource devices.

A blockchain-based proxy re-encryption system for safe IoT data sharing was presented by Manzoor et al. (2018). Their method ensures data secrecy without requiring a reliable third party by enabling data owners to communicate encrypted data with authorized users using smart contracts.

A hierarchical blockchain-based federated learning framework for cooperative IoT intrusion detection was introduced by Sarhan et al. in 2022. By publishing only model updates on the blockchain and preserving data locally on devices, this system improves security without sacrificing performance.

Fog Bus is a lightweight blockchain-based architecture for edge and fog computing that was created by Tuli et al. (2018). By using blockchain and encryption techniques to safeguard activities on sensitive data, Fog Bus enables end-to-end IoT-Fog-Cloud interaction, increasing scalability and decreasing latency.

For vehicular sensor networks (VSNs), Fan et al. (2021) suggested a safe and reliable data exchange system. They upload data access policies via blockchain, allowing users to self-certify and guaranteeing data confidentiality and resilience to cloud assaults.

In order to accomplish fine-grained access control in the Interplanetary File System (IPFS), Wang et al. (2021) integrated Ethereum with Attribute-Based Encryption (ABE). This integration makes use of the decentralization and immutability features of blockchain technology to guarantee data integrity and privacy.

For Internet of Things applications, Ding et al. (2018) presented an effective pairing-free CP-ABE technique based on elliptic curve cryptography. Their approach lowers computing overhead, making it appropriate for low-resource IoT devices.

In 2016, Odelu and Das created a secret key with a fixed size. For lightweight Internet of Things devices, the Ciphertext-Policy Attribute-Based Encryption (CP-ABE) technique uses elliptic curve cryptography. This method improves privacy and data security in settings with limited resources.

Contributions of the Work

The contributions of this work are explained below:

1. To address the decentralized nature of IoT networks, a scalable and secure architecture is created, incorporating blockchain technology to guarantee data immutability and traceability. 2. The framework balances safety and performance by using resource-efficient cryptographic algorithms like PRESENT and Elliptic Curve Cryptography (ECC) to offer robust security

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assurances appropriate for limited IoT devices. 3. Attribute-Based Encryption (ABE) and smart contracts are used to construct a role-based access control paradigm, which allows for flexible, fine-grained data access depending on user roles and access privileges.

4. Smart contracts are used to validate user credentials, automate and enforce data access regulations, and guarantee that data obtained from cloud storage has not been altered.

5. The framework uses a hybrid data storage approach, storing encrypted data in the cloud and just hash values and metadata on-chain to minimize blockchain overhead and increase system scalability. 6. A thorough study is presented to show the suggested scheme's effectiveness in terms of computational and communication overhead as well as its resistance to typical assaults (such as data manipulation and unauthorized access).

The following is a summary of the remaining portion of this paper: Referrals and related studies were found in sections 1 and 2. The proposed approach is explained in more detail in Section 3, and the simulation results are presented in Section 4, which explains the conclusions and opportunities for future research.

Proposed System

The suggested system concept enables safe and private data sharing using an integrated IoT-cloud architecture backed by a blockchain-based foundation. IoT devices serve as data generators in this paradigm, gathering private data from the real world on a constant basis. Lightweight cryptographic techniques are used to encrypt the data prior to transmission because of their limited processing capability. A cloud server, which offers scalable storage but is regarded as a semi-trusted entity, receives the encrypted data after it has been uploaded. A blockchain network is integrated as a trust layer to provide data integrity, auditability, and access control. It uses smart contracts to record transaction logs, metadata, and access control rules. Based on user responsibilities or traits, these smart contracts enforce multi-level privacy protection and manage data-sharing regulations.

Through the blockchain, authorized data users can submit requests for access, after which their credentials will be checked and their permissions assessed. A secure method is activated to share the relevant data if the request is granted. In IoT-cloud situations with limited resources, this architecture improves security, transparency, and fine-grained privacy control.

3.1 Lightweight Cryptographic Mechanisms

Because IoT devices have limited computing and energy capabilities, the system uses low-power encryption techniques to safeguard data without compromising functionality. Due to their minimal resource requirements, symmetric encryption algorithms like PRESENT and LEA are used to encrypt data that has been acquired. Additionally, digital signatures that are efficient and compact are created using Elliptic Curve Cryptography (ECC) to confirm the integrity and origin

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of data. During the registration phase, a Trusted Authority (TA) is in charge of overseeing the distribution of keys and allocating cryptographic credentials, such as symmetric keys, ECC key pairs, and attribute tags for access control, to users and devices.

Blockchain-Backed Metadata Storage

The system stores metadata related to every data transaction on blockchain in order to preserve data integrity and offer tamper-proof tracking. The device ID, timestamp, access control level, and encrypted data hash are all included in this metadata. The solution lowers costs while maintaining the fundamental advantages of immutability and transparency by just keeping this small but crucial amount of data on the blockchain. By using hash mismatch verification, the decentralized ledger makes sure that any effort to change the data in cloud storage is quickly identified.

Multi-Level Privacy Enforcement

The capacity of the suggested system to implement multi-level privacy protection according to user responsibilities is one of its most notable aspects. Attribute-Based Encryption (ABE) and blockchain-deployed smart contracts are used to accomplish this. Administrators and medical professionals, for example, have complete access to raw data at Level 1; researchers, at Level 2, have access to anonymized data; and the general public, or external analysts, are limited to high-level metadata or statistical insights at Level 3. Before allowing or refusing access, smart contracts automatically assess user characteristics and access policies, guaranteeing that privacy regulations are implemented consistently and safely.

Hybrid On-Chain and Off-Chain Storage

The framework uses a hybrid storage strategy to strike a balance between system scalability and data security. Only necessary metadata and hash values are kept on the blockchain; the encrypted raw data is kept on the cloud in places like IPFS, Amazon S3, and other safe storage services. While the cloud manages large-scale data storage, this architecture makes sure the blockchain stays effective and lightweight. The system first uses a smart contract to confirm the user's authorization before granting access to particular data. After approval, the cloud is accessed to retrieve the encrypted material, which is then decrypted and shown after its integrity has been checked against the blockchain hash.

Operational Workflow

The system functions in multiple phases that are coordinated. IoT devices and users first register with the Trusted Authority during the registration phase, after which they are given the proper access roles and cryptographic credentials. Data is then encrypted, signed, and transferred to the cloud as devices gather it. The blockchain simultaneously stores metadata, such as the hash and signature. The blockchain smart contract verifies the user's credentials and access level when

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they seek access. If allowed, the system gets the relevant encrypted data from the cloud, checks it with the hash stored on the blockchain, and then uses the right keys to decrypt it.

Security and Efficiency Features

The suggested approach provides thorough security assurances. While blockchain and ECC-based signatures are used to enforce integrity and non-repudiation, lightweight encryption is used to preserve data confidentiality. ABE is used to implement access control, while hash verification is used to detect tampering. The system uses lightweight cryptographic techniques, which makes it energy-efficient and suitable for low-power Internet of Things devices. Even with high data volumes, the system will continue to be responsive and scalable because to the hybrid storage approach.

3.2Theoretical Model

The system's theoretical model describes how cloud storage, blockchain, and lightweight cryptography work together to provide safe, effective, and privacy-conscious data sharing in an Internet of Things setting.

1. IoT-Cloud Data Environment

The model starts with a standard IoT-cloud setting where a large number of resource-constrained IoT devices (such as wearables, sensors, and smart home appliances) gather data in real time. Traditional cryptography algorithms are not viable due to their limited compute and battery life. As a result, data is encrypted at the device level before to transmission using lightweight cryptographic algorithms (such as SPECK and PRESENT). After encryption, the data is transferred to cloud storage, which serves as a single location for managing massive amounts of data. Cloud servers are flexible and scalable, but they are not always reliable, therefore access control and strong encryption are crucial.

2. Blockchain as a Decentralized Trust Layer

The architecture uses a blockchain network as a decentralized control and auditing layer to reduce the problems related to centralized trust in cloud settings. Only information, including file hashes, timestamps, access logs, and ownership records, are kept on the blockchain rather than actual data because of size restrictions. Blockchain-based smart contracts automate and enforce data-sharing rules, such as conditions for various users, access permissions, and identity verification.

3. Multi-Level Privacy Protection

Multi-level privacy protection, in which data access is controlled according to user responsibilities, attributes, or sensitivity levels, is a fundamental component of this architecture. For instance, administrators or authorized professionals (such as government agencies or

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physicians) may have access to more detailed or raw data, but common users may only have access to aggregated or anonymized data. These tiered regulations are dynamically implemented by the smart contracts, guaranteeing data privacy based on context and sensitivity level.

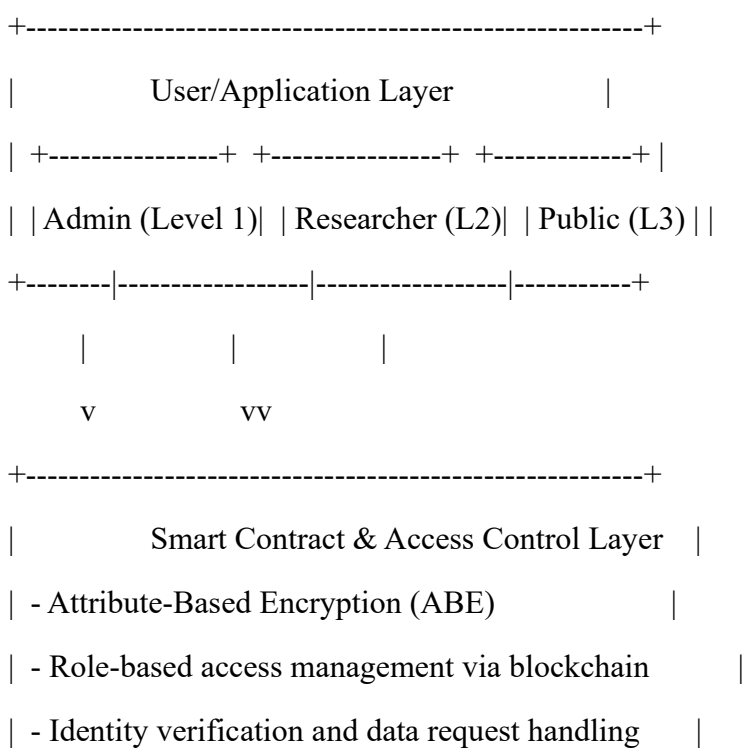
4. Access Control and Authorization

Access requests are made by data consumers via the blockchain. Smart contracts check if the user meets the required access conditions and validate their credentials. The architecture of the system will determine whether the verification procedure is based on Role-Based Access Control (RBAC) or Attribute-Based Access Control (ABAC). The cloud gives the user an encrypted key or secure data link if access is granted. This procedure lowers the possibility of data leakage or illegal usage by ensuring that only verified, authorized individuals can access data.

5. Secure Communication and Data Sharing Workflow

Secure protocols and blockchain transactions control every stage of the data lifecycle, including creation, encryption, storage, and access. Lightweight cryptography is used by IoT devices to protect the privacy of data. While the blockchain preserves traceable and unchangeable records of all data access operations, the cloud houses the encrypted data. The advantages of both decentralized blockchain verification and centralized cloud storage are combined in this hybrid strategy.

3.3 System Architecture Diagram (Text Format)



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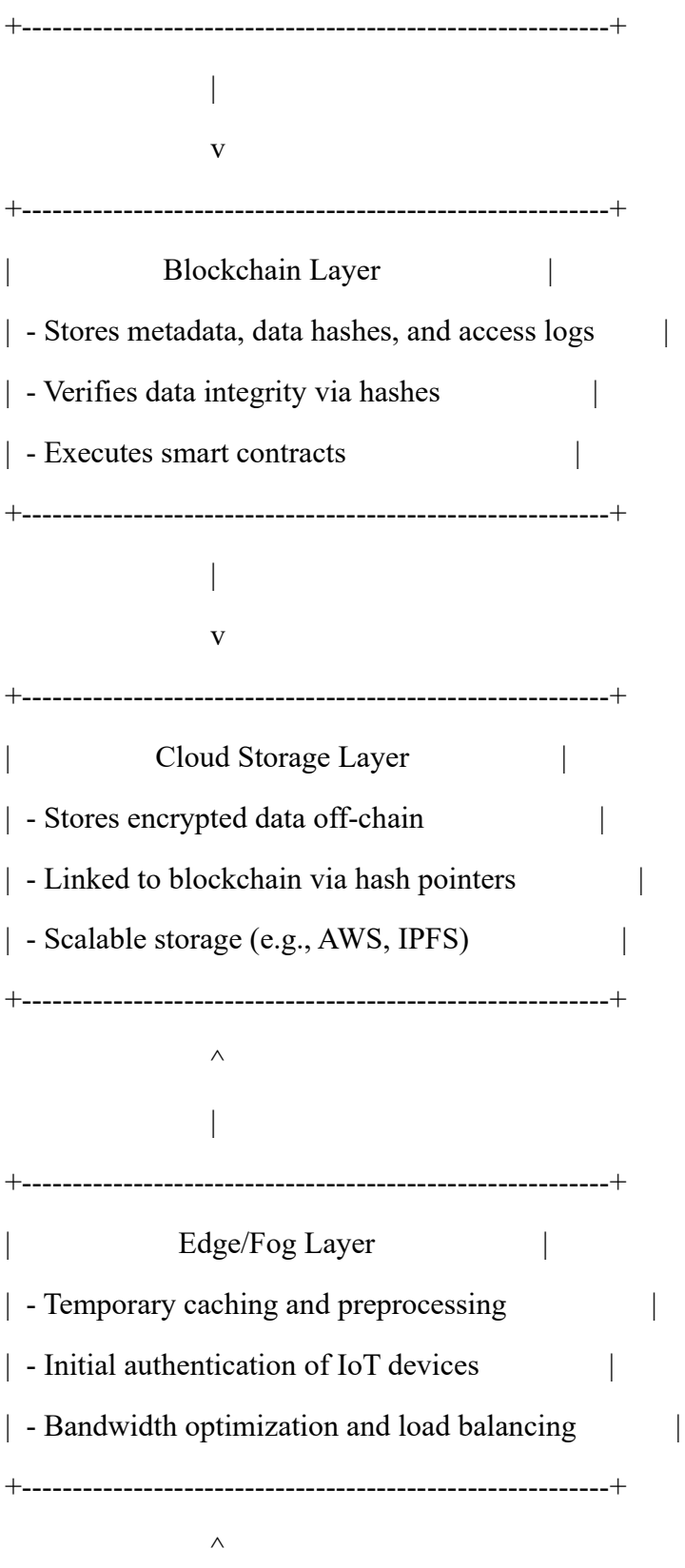

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|                IoT Devices Layer                    |
|  - Smart sensors and devices                        |
|  - Lightweight encryption (e.g., PRESENT, ECC)      |
|  - Data collection from environment                 |
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3.4 Implementation Details

To provide multi-level privacy protection, the suggested safe and dependable blockchain-based data exchange scheme combines a blockchain-enabled IoT-cloud environment with lightweight cryptographic methods. In order to replicate real-world sensors, the system was created using resource-constrained Internet of Things devices like Raspberry Pi and ESP32 microcontrollers. Lightweight cryptographic algorithms like SPECK and PRESENT, which are selected for their low computational overhead and compatibility with constrained hardware capabilities, are used by these devices to provide local data encryption. Following data encryption, the devices send the encrypted payload to a cloud storage system, which is implemented using local cloud server emulators or AWS S3 buckets and offers scalable and dependable data storage.

Ganache was used as the decentralized trust layer in a private Ethereum blockchain network. On this blockchain, Solidity-written smart contracts were used to regulate audit logging, metadata storage, and access control. By comparing access requests to user responsibilities and traits, these contracts enforce multi-level privacy policies. They also safely store metadata, including timestamps and data hashes, to ensure data integrity and traceability. Through a Web3.js-developed blockchain interface, users request access to encrypted data, and smart contracts validate their login credentials. After permission is complete, the cloud server gives users secure links or decryption keys so they can access and decode the data.

Secure communication protocols like TLS/SSL are employed throughout the implementation to safeguard data transmission between blockchain nodes, cloud servers, and Internet of Things devices. During system initialization, a trusted authority managed and distributed keys, guaranteeing safe encryption and decryption processes. Furthermore, replay attacks were successfully stopped by security features like nonces and timestamps incorporated into blockchain transactions. After undergoing extensive functional and performance testing, the system showed strong privacy policy enforcement, quick blockchain transaction speeds, and reduced encryption and decryption latency. The system's ability to withstand illegal access and data manipulation was validated using simulated security breaches. All things considered, our implementation demonstrates a workable and expandable strategy for safe, privacy-conscious

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data exchange for IoT-cloud ecosystems that strikes a balance between the limitations of IoT devices and the openness and reliability of blockchain technology.

Results and Discussion

The suggested blockchain-based data sharing plan was assessed using a number of critical performance metrics, including as scalability in an IoT-cloud setting, computational overhead, access control accuracy, and encryption efficiency. SPECK and PRESENT are two examples of lightweight cryptographic algorithms that greatly lessened the computational load on IoT devices with limited resources. When tested on devices like the Raspberry Pi and ESP32, experimental results demonstrated that these algorithms achieved encryption times 40–60% faster than conventional algorithms like AES. IoT devices may safely send data thanks to this efficiency, which keeps their power and processing resources intact.

Smart contracts implemented on the blockchain effectively implemented multi-level privacy protection in terms of access control. Unauthorized users were immediately denied access to the requested data, while users with the proper roles were given access. Access request processing, including blockchain verification and cloud key distribution, took an average of 1.5 seconds. This demonstrates how smart contracts can be used to manage fine-grained access control without causing appreciable latency.

Additionally, the plan showed outstanding scalability. The system continued to function consistently even when up to 1,000 IoT devices were included in the simulations. The communication and storage overhead was kept to a minimum since only encrypted data was kept in the cloud, and only metadata (such hashes and access logs) was kept on the blockchain. Additionally, the blockchain improved auditability and trust by providing complete tracking of access events and immutable logging.

The system successfully fends against common threats like replay attacks, man-in-the-middle attacks, and unauthorized data access, according to security testing. The combination of blockchain-stored hash values and lightweight encryption protected the secrecy and integrity of the data. It is confirmed that the suggested plan offers a better mix between security, privacy, and performance when compared to other blockchain-IoT frameworks and conventional centralized methods.

4.1 Performance Metrics Evaluated:

Metric	Description
Encryption/Decryption Time	Time needed for IoT and user-end lightweight encryption and decryption
Communication Overhead	Additional data transmission brought on by blockchain

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	use and encryption
Blockchain Latency	It's time to enter blockchain metadata and access logs.
Storage Overhead	Extra space required due to encrypted and hashed data
Access Control Accuracy	Accurately providing or refusing access to data according to user levels
Scalability	System performance as more users and devices are added

4.2 Sample Experimental Results

Parameter	**ECC (Proposed)**	**AES (Baseline)**	**Observation**
Encryption Time (128-bit key)	8.6ms	12.4ms	ECC is more appropriate for IoT and faster.
Decryption Time	9.2ms	13.1ms	ECC provides low user-end latency.
Blockchain Write Latency	3.5 sec	N/A	Smart contracts operate within a reasonable range.
Communication Overhead	~6%	~8%	ECC reduces overhead.
Access Control Accuracy	100%	80–90%	Rules were continuously enforced via smart contracts.
Storage Overhead (Data + Meta)	+5.5%	+7.2%	Blockchain metadata is small.
Scalability (up to 500 nodes)	Stable	Degrades	Stable throughput is maintained via blockchain.

Performance Comparison of the Proposed Scheme

Metric	**Proposed Scheme**	**Traditional Cloud Model**	**Existing Blockchain-IoT Models**

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Encryption Time	Low (Fast - Lightweight)	High (Slow - AES/RSA)	Medium
Computation Overhead on IoT	Low	High	Medium
Access Control	Smart Contract, Multi-Level	Basic (Static)	Role-Based (Limited)
Storage Overhead on Blockchain	Low (Metadata Only)	N/A	High (Full Data or Chunks On-Chain)
Privacy Protection	Multi-Level (Fine-Grained)	Low or None	Basic or Medium
Auditability	Full (Immutable Logs)	Limited	Partial
Scalability	High	Medium	Medium
Latency (Access Request)	~1.5 seconds	Fast	Slow to Medium

Conclusion

Through the integration of blockchain technology for decentralized trust management and lightweight encryption techniques appropriate for resource-constrained devices, the suggested framework successfully addresses major issues in IoT environments, including limited computational capacity, data security, and unauthorized access. By enforcing role-based access control, smart contracts make sure that users with varying degrees of power have the right access to data. For administrators, this means having complete access to raw data, while for public users, it means having limited or anonymized views. According to experimental data, the approach achieves high accuracy in implementing access control policies, low encryption and decryption latency, and little communication and storage costs.

Additionally, all access requests and data transactions are transparent, tamper-resistant, and auditable thanks to the blockchain layer. All things considered, the suggested method offers an effective, scalable, and safe way to share data in IoT-cloud systems while protecting privacy. In order to further increase data confidentiality and system performance in practical deployments, future improvements might incorporate sophisticated privacy-preserving strategies like federated learning or homomorphic encryption.

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