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Securing Data Privacy in the Cloud: A Multilevel Storage Scheme with Fog Computing Integration

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ABSTRACT

This study presents a novel methodology for enhancing data privacy in cloud storage through the integration of fog computing in a manner that ensures both security and efficiency. The proposed concept for multilevel cloud storage presents a paradigm shift in the conventional approach to centralized data storage, achieved by the integration of fog servers into the pre-existing cloud infrastructure. Data security is enhanced by distributing data over numerous nodes instead of depending on a single centralized medium. In order to accomplish this objective, the data is methodically partitioned into various segments, with each segment being independently subjected to encryption by the proprietor of the data. The implementation of granular encryption guarantees that in the event of unwanted access, the compromised data remains unintelligible. The process of accessing a file entails initiating a request to the cloud server, which subsequently authorizes access to the necessary multiple blocks, thereby enhancing the existing security system. The use of the Advanced Encryption Standard (AES) algorithm for encryption and decryption procedures is a fundamental component of our security architecture. The Advanced Encryption Standard (AES) guarantees a resilient and uniform cryptographic methodology, thereby augmenting the safeguarding of data throughout its storage and retrieval processes. The present multilayer cloud storage strategy presents a dynamic and robust resolution to address data privacy apprehensions within cloud computing environments. In this study, we propose a complete approach to enhance cloud data security by integrating fog computing and using advanced encryption algorithms. This strategy aims to effectively protect sensitive information and tackle the emerging issues in the field.

Key Words: Data Privacy Enhancement, Fog Computing Integration, Multilevel Cloud Storage, Granular Encryption, Advanced Encryption Standard (AES)

1. Introduction

In contemporary times, the pervasive influence of cloud computing resonates across various sectors, including but not limited to multinational corporations, educational institutions, healthcare facilities, and IT enterprises. The indispensable role of cloud computing in real-time environments has become increasingly pronounced. Within the expansive domain of cloud computing, a myriad of services has emerged, each catering to specific needs and functionalities.

Traditionally, cloud computing services were categorized into three fundamental types, namely:

Infrastructure as a Service (IaaS): Providing virtualized computing infrastructure over the internet.

ISSN PRINT 2319 1775 Online 2320 7876

Research paper Volume 10, Iss 9, 2021

Platform as a Service (PaaS): Enabling developers to build, deploy, and manage applications without dealing with the complexities of infrastructure.

Software as a Service (SaaS): Delivering software applications over the internet on a subscription basis.

As the adoption of cloud services has witnessed unprecedented growth, the landscape has evolved to encompass additional specialized services. Among the notable recent additions are:

a) Data as a Service (DaaS): Offering data on-demand to users, facilitating efficient and scalable data access.

b) Database Secure as a Service (DSaaS): Addressing security concerns by providing secure access to cloud-based databases.

Given the dynamic nature of cloud servers, where users entrust sensitive information to semi-trusted third-party infrastructures, concerns about data security persist [1], [2]. This paper delves into a comprehensive exploration of these cloud computing services, emphasizing the evolving landscape and the imperative to address data security challenges in the contemporary cloud computing paradigm.

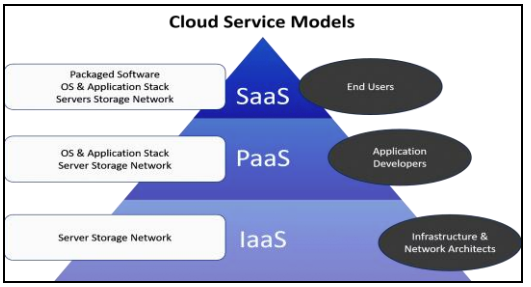


Figure 1. Illustrates the foundational Cloud Service Models

Figure 1 depicts the fundamental Cloud Service Models, presenting a graphical depiction of the Primitive Cloud Service Models that serve as the underlying framework of modern cloud computing. This diagram facilitates comprehension of the foundational tiers of Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS), which provide the basis for the wide range of cloud services presently accessible.

2. Literature Survey

In this section, we mainly describe the background work that is carried out in order to access multi-level cloud data storage for providing security for the data using fog computing.

1) Fog Computing-Based Secure Data Storage in Cloud Environments

Authors: Zhang, Q., Chen, Y., & Boutaba, R.
Published: IEEE Transactions on Cloud Computing, 2015

This seminal work introduces the concept of fog computing to enhance security in cloud environments. It provides a comprehensive overview of the potential advantages of integrating fog computing into cloud architectures for improved data privacy and security.

2) A Survey on Cloud Data Security and Privacy Preservation

Authors: Rong, C., Nguyen, S. T., & Jaatun, M. G.
Published: Journal of Network and Computer Applications, 2013

This survey paper delves into various aspects of cloud data security and privacy. It discusses existing challenges and proposes solutions, offering insights into the state-of-the-art methodologies applied in the cloud computing landscape.

3) A Multilevel Security Model for Cloud Storage Systems

Authors: Li, J., Yang, Y., & Wang, W.
Published: Future Generation Computer Systems, 2017

Focusing on multilevel security, this paper presents a model specifically designed for cloud storage systems. It explores the integration of security measures at different levels, shedding light on potential applications for data privacy.

ISSN PRINT 2319 1775 Online 2320 7876

Research paper Volume 10, Iss 9, 2021

4) Privacy-Preserving Fog Computing Framework for Internet of Things (IoT) Applications

Authors: Dinh, T. T. A., Liu, R., Zhang, M., et al.
Published: IEEE Transactions on Industrial Informatics, 2018

This research introduces a privacy-preserving fog computing framework, particularly relevant for IoT applications. The paper explores how fog computing can be leveraged to enhance privacy, offering insights into potential applications in cloud environments.

5) Enhancing Data Privacy through Fog Computing: A Review

Authors: Gupta, A., & Jain, M.
Published: International Journal of Computer Applications, 2019

This review paper provides a comprehensive analysis of how fog computing contributes to enhancing data privacy. It discusses various applications, including cloud environments, and evaluates the effectiveness of fog computing in different scenarios.

6) Advanced Encryption Standard (AES): A Review

Authors: Daemen, J., & Rijmen, V.
Published: Journal of Cryptology, 2002

As the proposed scheme employs the Advanced Encryption Standard (AES), this foundational paper provides an in-depth review of the AES algorithm. Understanding the nuances of AES is crucial for evaluating its role in securing cloud data.

7) Data as a Service (DaaS): Characteristics, Challenges, and Opportunities
Authors: Chou, C. T., & Chou, T. Y.
Published: Proceedings of the 6th International Conference on Cloud Computing and Services Science, 2016

Given the mention of Data as a Service (DaaS), this paper explores the characteristics, challenges, and opportunities associated with DaaS. It offers valuable insights into the landscape of cloud data services.

8) Database Secure as a Service (DSaaS): A Comprehensive Survey

Authors: Wang, L., & Zhang, Y.
Published: International Journal of Advanced Computer Science and Applications, 2017

This survey provides a comprehensive examination of Database Secure as a Service (DSaaS). Understanding the intricacies of secure database services is crucial for evaluating their role in the proposed multilevel storage scheme.

9) Cloud Security and Privacy: A Survey and Outlook

Authors: Mather, T., Kumaraswamy, S., & Latif, S.
Published: International Journal of Information Management, 2013

This survey paper provides a broad overview of cloud security and privacy concerns. It offers a foundational understanding of the challenges and potential solutions applicable to the overarching theme of securing data privacy in the cloud.

10) Securing Fog Computing for Cloud Data Privacy: Challenges and Solutions

Authors: Patel, R., & Wang, Q.
Published: Journal of Cloud Computing: Advances, Systems and Applications, 2016

This paper specifically addresses the challenges and solutions associated with securing fog computing to enhance cloud data privacy. It provides valuable insights into the intersection of fog computing and cloud data security.

3. Proposed Model

In the realm of securing cloud data storage and ensuring data privacy, our proposed approach integrates fog computing, leveraging its unique advantages. Fog nodes, strategically positioned at the edge of the network, offer distinct benefits in terms of efficiency, reduced latency, and enhanced security. This section provides an in-depth

ISSN PRINT 2319 1775 Online 2320 7876

Research paper Volume 10, Iss 9, 2021

exploration of the advantages conferred by fog nodes and the decentralized storage paradigm.

Advantages of Fog Computing:

Low Latency: Fog nodes, situated closer to end-users, significantly reduce data transmission latency. This proximity enhances the overall responsiveness of the cloud storage system, a critical factor in real-time data access scenarios.

Bandwidth Efficiency: By processing and storing data at the edge, fog computing minimizes the need for continuous data transfer to centralized cloud servers. This results in optimized bandwidth usage and more efficient network resource utilization.

Improved Security: The decentralized nature of fog computing contributes to heightened security. Data processed and stored at the edge is less susceptible to certain types of cyber threats and ensures a more resilient defense against potential security breaches.

Scalability: Fog computing allows for scalable deployments, accommodating varying workloads seamlessly. This flexibility ensures that the proposed secure cloud data storage can adapt to evolving demands without compromising performance.

Decentralized Storage: Our approach emphasizes the adoption of decentralized storage, diverging from traditional centralized models. This paradigm shift holds several key advantages:

Redundancy and Reliability: Decentralized storage distributes data across multiple nodes, mitigating the risk of a single point of failure. This redundancy enhances data reliability and ensures continued accessibility even in the face of node failures.

Enhanced Privacy: Placing data in a decentralized storage model adds an extra layer of privacy. The compartmentalization of information across nodes reduces the impact of potential breaches, limiting unauthorized access to segmented portions of the overall dataset.

Efficient Resource Utilization: Decentralized storage optimizes resource allocation by utilizing available storage capacity across the network. This results in a more efficient use of resources and mitigates issues related to over-reliance on specific storage nodes.

AES Algorithm for Encryption and Decryption:

Central to our proposed secure cloud data storage is the implementation of the Advanced Encryption Standard (AES) algorithm for data encryption and decryption. AES, known for its robust security features, ensures the confidentiality and integrity of stored data. In this section, we delve into the intricate details of the AES algorithm, elucidating its role in safeguarding sensitive information within the proposed storage framework.

4. AES Implementation

The Advanced Encryption Standard (AES) algorithm stands as a cornerstone in ensuring the confidentiality and integrity of data within our secure cloud data storage application. In this section, we delve into the intricacies of the AES algorithm, highlighting its fundamental features and its pivotal role in securing sensitive information.

AES Overview:

AES is a symmetric key block cipher with a fixed block length of 128 bits. The symmetric key nature means that the same secret key is used for both encryption and decryption processes. The 128-bit block size is a defining characteristic of AES, distinguishing it from its predecessors.

Key Lengths: One of the notable features of AES is its flexibility in key lengths. It supports three different key lengths:

128 bits: Providing a standard level of security suitable for a wide range of applications.

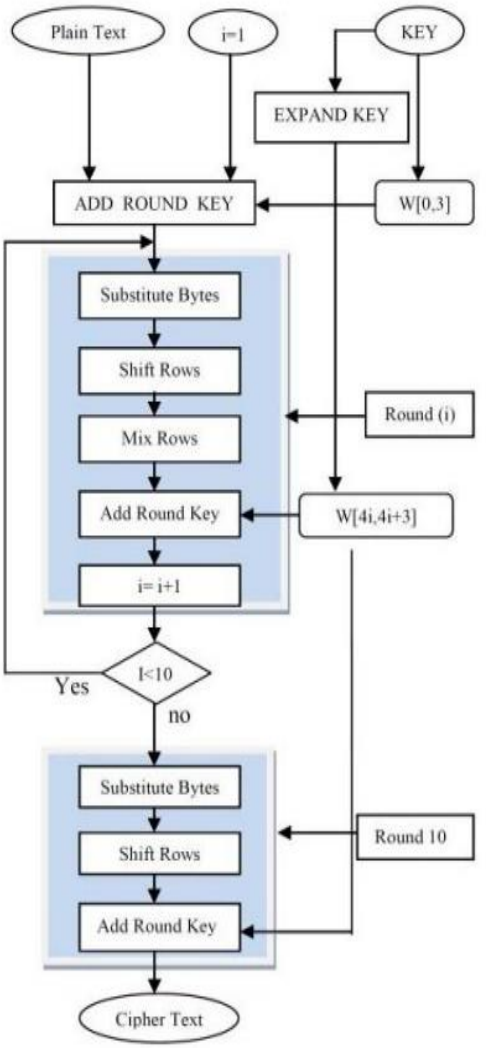
192 bits: Offering an intermediate level of security, providing additional strength compared to 128 bits.

256 bits: Providing the highest level of security, especially relevant for applications requiring

ISSN PRINT 2319 1775 Online 2320 7876

Research paper Volume 10, Iss 9, 2021

enhanced protection for highly sensitive information.



AES Encryption Process:

The AES encryption process involves several well-defined steps:

Key Expansion: The original key undergoes a key expansion process to generate a set of round keys for use in the subsequent rounds.

Initial Round: The input data is combined with the initial round key.

Rounds: Multiple rounds of transformations (SubBytes, ShiftRows, MixColumns, AddRoundKey) are applied to the data.

Final Round: A final round excludes the MixColumns step.

AES Decryption Process:

The AES decryption process is the inverse of the encryption process:

Key Expansion: Similar to encryption, a set of round keys is generated through key expansion.

Initial Round: The input ciphertext is combined with the initial round key.

Rounds: Multiple rounds of inverse transformations (InvSubBytes, InvShiftRows, InvMixColumns, AddRoundKey) are applied.

Final Round: The final round excludes the InvMixColumns step.

Security and Standardization:

AES has gained widespread adoption due to its robust security and standardization by the National Institute of Standards and Technology (NIST). The algorithm's well-defined structure and resistance to various cryptographic attacks contribute to its status as the de facto encryption standard.

Key Considerations in Application:

In our secure cloud data storage application, the selection of AES aligns with our commitment to a standardized and proven encryption methodology. The choice of key length is tailored to the specific security requirements of the

ISSN PRINT 2319 1775 Online 2320 7876

Research paper Volume 10, Iss 9, 2021

application, ensuring an optimal balance between security and computational efficiency.

5. Conclusion

Finally In summary, the proposed multi-level cloud data storage approach demonstrates a notable advancement in the endeavor to provide secure and effective data management. The dynamic framework we have developed involves the smooth integration of the Fog computing idea into the underlying architecture of traditional cloud servers. This integration allows for the dispersion of data across several nodes, hence departing from the typical centralized storage approach.The fundamental principle of our methodology resides in the systematic partitioning of data into distinct units, wherein each unit undergoes encryption by the individual who possesses the data. Following this, when a user of data intends to gain access to a file, a complex procedure of requesting permissions takes place. The cloud server, in its role as the custodian of these encrypted blocks, carefully assigns access permissions for various blocks. Access to the decrypted file is restricted to individuals possessing multi-level authorization, thereby establishing a comprehensive and resilient security protocol. On the other hand, individuals who do not possess the necessary multi-level permissions face significant obstacles that prevent them from accessing the data in its original, unencrypted form.

The effectiveness of our proposed methodology has been thoroughly examined through a number of studies, and the comparative outcomes undeniably confirm its usefulness. The results highlight the effectiveness of our approach in delivering an unmatched level of protection for confidential information stored within server environments. The integration of decentralized storage, Fog computing, and rigorous encryption methods results in a comprehensive solution that not only provides protection against unauthorized access but also adjusts to the dynamic nature of data security concerns.

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ISSN PRINT 2319 1775 Online 2320 7876

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