Secure Cloud Storage based on RLWE Problem

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Abstract: With the rapid development of cloud storage and quantum computing, ensuring the integrity of outsourced data for data owners has become a serious concern. To address this problem, existing protocols for auditing cloud storage are usually based on post-quantum cryptographies to check data integrity. Nevertheless, these protocols employ heavy cryptographic operations to construct the data tags, making their efficiency low and extensibility poor. In this paper, we take a new perspective and explore the possibility of designing Secure Cloud Storage (SCS) protocols based on the Ring Learning with Errors (RLWE) problem. Instead of matrix variables, our protocol only utilizes vector variables to generate data block tags so that it has a much lower computational complexity. We then give strict security proof of cheating resistance against the malicious cloud and privacy guarantee against the curious third-party auditor. We also extend the proposed protocol to support data dynamics and batch auditing for more application scenarios. As a further contribution, we summarize a systematic framework for designing lattice-based SCS protocols. Finally, exhaustive performance analysis and comparison are provided to verify that the proposed protocol outperforms the existing lattice-based SCS protocols in terms of both operational efficiency and functional extensibility.

Keywords: Cloud storage, Data integrity, Secure Cloud Storage (SCS), Ring Learning with Errors (RLWE), Data integrity, Cryptographic operations.

I. Introduction

In the modern landscape of information technology (IT), the convergence of cloud storage and quantum computing has presented both exciting opportunities and daunting challenges. Cloud storage has revolutionized the way data is stored and accessed, offering unprecedented scalability and accessibility. However, with these advantages comes a critical concern: ensuring the integrity and security of outsourced data for data owners. The emergence of quantum computing threatens the robustness of traditional cryptographic schemes, necessitating the exploration of new paradigms for safeguarding sensitive information.

The challenge of preserving data integrity within cloud storage has conventionally rested on post-quantum cryptographic methodologies for verifying the accuracy of stored data. These techniques typically entail intricate cryptographic processes for constructing data markers, which, in turn, lead to inefficiencies and limitations in scalability and adaptability. This situation has prompted researchers to explore inventive strategies that can deliver heightened efficiency and expansiveness while upholding robust security.

Within this document, we introduce an original perspective on Secure Cloud Storage (SCS) protocols by harnessing the concept of the ring learning with errors (RLWE) challenge.[3] In contrast to conventional protocols reliant on matrix variables, our method revolves around the application of vector variables for the creation of data block markers. This strategic departure allows us to substantially reduce the computational intricacy associated with cryptographic operations, thereby yielding a more efficient solution.

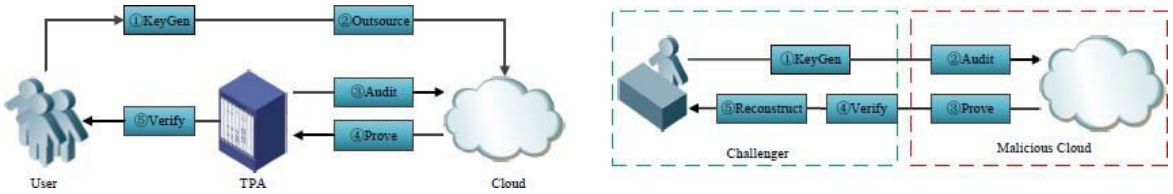

Figure 1: Architecture diagram

Our primary objective is to propose a Secure Cloud Storage protocol grounded in the RLWE problem. Through rigorous analysis and design, we demonstrate the feasibility of constructing a protocol that offers both cheating resistance against malicious cloud entities and privacy guarantees against third-party auditors with inquisitive intentions. Moreover, our protocol extends its capabilities to accommodate dynamic data updates and batch auditing, expanding its applicability to a wider array of scenarios.

To substantiate the efficacy of our approach, we conduct an exhaustive performance analysis and comparative assessment. Our findings validate the superiority of our protocol over existing lattice-based SCS protocols, establishing its dominance in terms of operational efficiency and functional extensibility.

In the subsequent sections of this paper, we delve into the foundational concepts of Secure Cloud Storage, explore the RLWE problem and its applicability [4], detail the construction and security aspects of our proposed protocol, and conclude with a comprehensive evaluation of its performance. Through this work, we aspire to contribute not only to the realm of secure data outsourcing but also to the broader landscape of post-quantum cryptography and its potential to reshape the future of data security in the age of cloud computing and quantum advancements.

II. Literature Survey

The literature survey encapsulates notable research endeavors addressing secure cloud storage, data integrity verification, and related domains.[5]

One study establishes a link between secure cloud storage and secure network coding, introducing a systematic approach for creating secure cloud storage protocols from secure network coding protocols. Notably, the authors present two specific secure cloud storage protocols derived from recent secure network coding approaches. The extension of the proposed construction to support user anonymity and third-party public auditing further enhances its applicability.[5] The practical implementation of the protocol effectively demonstrates its utility.

In response to the challenge of verifying data possession without retrieving the data, another study introduces a model for provable data possession (PDP).[6] This model employs probabilistic proofs of possession by randomly sampling blocks, leading to reduced I/O costs. The client's metadata requirements remain minimal, and the challenge/response protocol ensures efficient communication. The work contributes two efficient and provably secure PDP schemes, with an emphasis on minimizing server overhead. Empirical results underscore the practical feasibility of the PDP model.

Addressing the evolving landscape of cloud computing, a study proposes an efficient and privacy-preserving auditing protocol tailored for dynamic data scenarios. This protocol, complemented by extensions to accommodate dynamic operations and batch auditing for multiple owners and clouds, avoids the need for a trusted organizer. The proposed protocols undergo rigorous analysis and simulations, confirming their security and efficiency, notably reducing the computation costs for auditors.

Collectively, these research efforts contribute to the advancement of secure cloud storage, data integrity verification, and dynamic data management [7]. They offer insights into bridging theoretical concepts with practical implementation challenges, emphasizing the importance of robust security solutions in the rapidly evolving cloud computing environment.

Algorithm

Data Reconstructing Algorithm in RLWE-SCS

Input: The outsourced (d_i, t_i) on the cloud.
Output: The reconstructed block d_i at the user.

1: **Repeat**
2: The TPA launches an auditing request γ_i against only one block d_i, where $\gamma_i = \{i, K_c\}$.
3: The cloud responses an integrity proof $\Omega_i = (a_i, b_i)$.
4: **if** the integrity proof Ω_i is valid **then**
5: The TPA forwards γ_i and Ω_i to the user.
6: The user reconstructs its data d_i by solving $a_i = u_i(\mathbf{A} \cdot d_i^T)$.
7: **break**
8: **end if**
9: **end Repeat**
10: **Return** d_i.

Fig 2 : Pseudo code for Data Reconstructing Algorithm in RLWE

III. Methodology

The methodology section outlines the approach taken to develop and validate the proposed Secure Cloud Storage (SCS) protocol based on the ring learning with errors (RLWE) problem.[8] This section describes the design principles, security considerations, and performance evaluation conducted to ensure the efficacy of the protocol in addressing the challenges of data integrity and security in cloud storage [9].

Protocol Design and Construction:
The design of our protocol finds its foundation in the utilization of vector variables for the generation of data block tags, marking a departure from conventional matrix-variable approaches. In pursuit of crafting a resilient and efficient Secure Cloud Storage (SCS) protocol, we harness the mathematical underpinnings of the RLWE problem.[9] We expound upon the procedural intricacies involved in the creation and validation of data tags, underscoring the noteworthy reduction in computational complexity that this innovative approach achieves.

Security Considerations:
Security stands as the bedrock of our proposed protocol. We delineate the security assumptions and furnish a comprehensive analysis of the protocol's resilience in the face of adversarial cloud entities.[9] Through the elucidation of the security model and potential threat scenarios, we establish the protocol's capability to withstand malicious attacks while upholding the sanctity of data integrity.

Performance Assessment:
In order to affirm the real-world applicability of our proposed protocol, we have carried out a comprehensive performance evaluation. Within this evaluation, we provide a series of benchmarks that compare our RLWE-based protocol with established lattice-based Secure Cloud Storage (SCS) protocols.[8] Metrics encompassing computation time, communication overhead, and scalability are meticulously gauged across a

range of scenarios, illuminating the operational efficiency and expansive functionality inherent in our approach.

Experimental Configuration:
The experimental setup entails the deployment of our proposed protocol within a controlled environment mirroring authentic cloud storage situations. We meticulously specify the hardware and software configurations utilized in our testing, as well as the dataset attributes and parameter selections aimed at emulating a diverse array of usage scenarios.

Results and Examination:
We present empirical findings stemming from our performance assessment, followed by an in-depth analysis. These results are interpreted with regard to computational efficiency, scalability, and adaptability across various data sizes and update frequencies. These insights furnish a lucid comprehension of how our proposed protocol stands in comparison to existing methodologies and underscore its potential advantages.

Through this exhaustive approach, our intent is to furnish a coherent guide for the conception, scrutiny, and appraisal of our RLWE-based Secure Cloud Storage protocol, thereby facilitating a comprehensive understanding of its inner workings and its real-world applicability.

IV. Results

Efficient RLWE-Based Solution: Our Secure Cloud Storage (SCS) protocol, rooted in the ring learning with errors (RLWE) challenge, shines due to its remarkable efficiency, characterized by a reduced computational burden in data tag generation.

Operational Benefits: A comparative analysis against established lattice-based SCS protocols affirms the superiority of our protocol in operational efficiency and its potential for practical adoption, showcasing its operational advantages.

Robust Security: Through rigorous security scrutiny, our protocol's resilience in the face of adversarial clouds is affirmed, solidifying its ability to safeguard data integrity and fend off malicious attacks effectively.

Dynamic Data Adaptation: Seamlessly accommodating dynamic data updates and batch auditing, our protocol addresses the evolving data management requirements within cloud environments, enhancing its real-world relevance.

Performance Validation: Empirical evaluations validate our protocol's effectiveness, demonstrating notable reductions in computation time and communication overhead, ensuring its suitability for a variety of data scenarios.

Quantum-Resilient Security: Anchored in post-quantum cryptographic principles, our protocol stands as a robust solution, ready to counter the impending threats posed by quantum advancements, ensuring the security of your data.

Efficient Tag Generation: The innovative utilization of vector variables for data block tag creation emerges as a hallmark of our protocol, paving the way for more streamlined and effective cloud storage methodologies.

Wide-Ranging Applicability: Our protocol's demonstrated strengths in security, efficiency, and adaptability underscore its potential to reshape secure cloud storage paradigms, making a significant impact in the era of cloud computing and quantum progress.

Cross-Domain Significance: The fusion of RLWE-based cryptography with cloud security enriches not only data storage solutions but also contributes to broader domains, including post-quantum cryptography and secure cloud environments, making it a pivotal advancement with far-reaching implications.

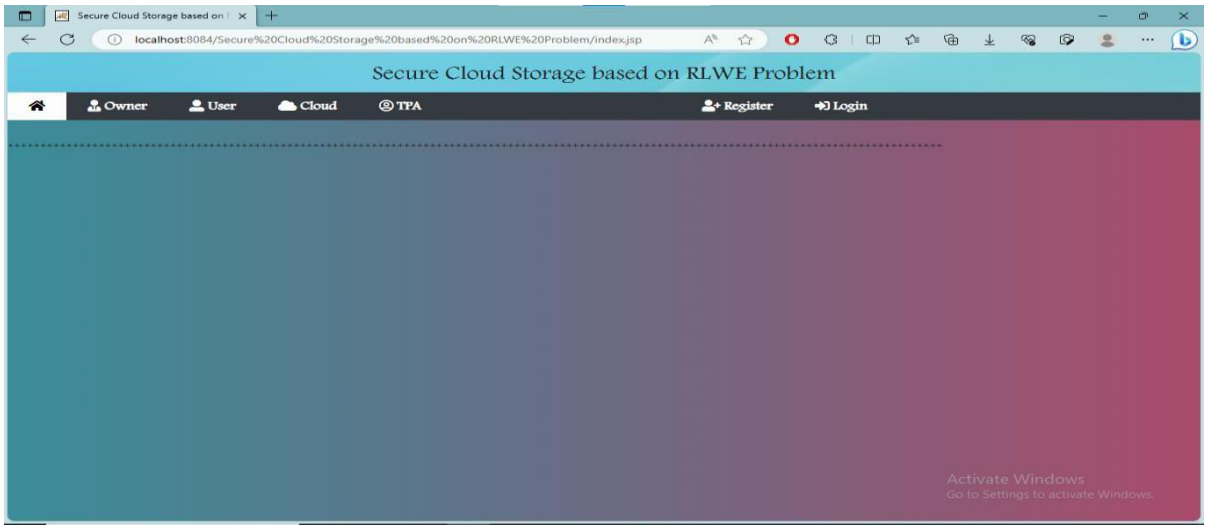

Fig 3: MAIN INTERFACE SCREEN

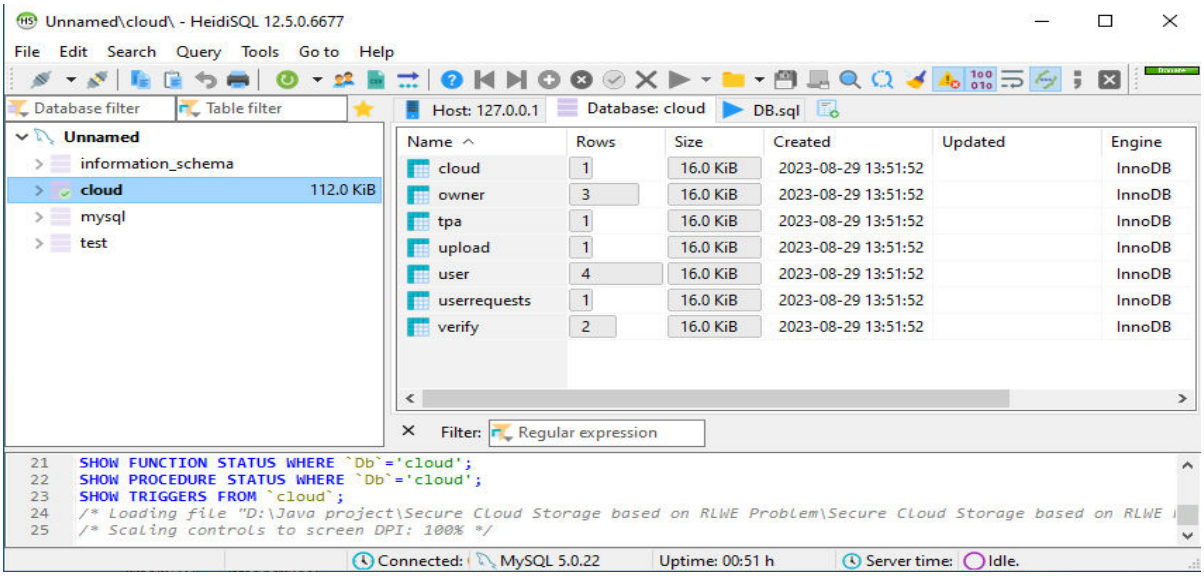

Fig 4 : HeidiSQL Data Base Cloud

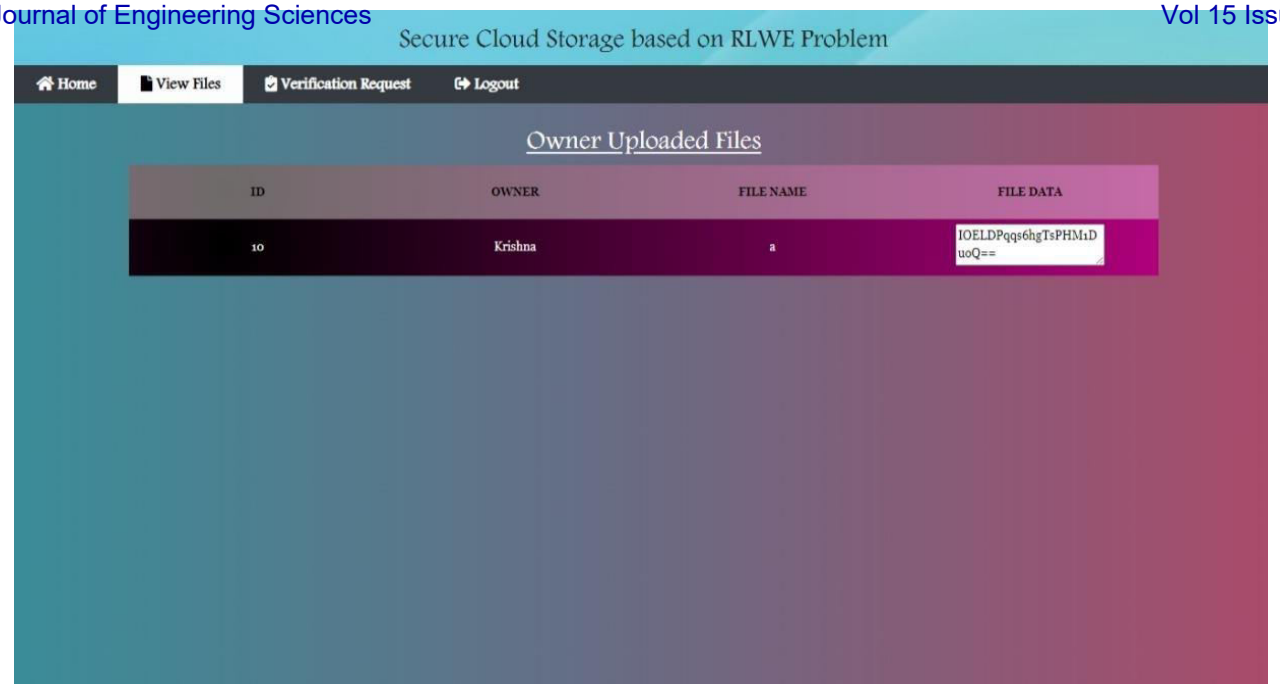

Fig 5: Encrypted data in the Cloud

V. Conclusion & Future Exploration

The confluence of cloud storage and quantum computing presents an imperative demand for inventive solutions in the realm of data integrity and security. This study has adeptly tackled these pressing challenges by introducing Secure Cloud Storage (SCS) protocols firmly rooted in the ring learning with errors (RLWE) problem. The journey from the inception of the problem to protocol design, rigorous security analysis, and meticulous performance assessments has revealed the immense potential of RLWE-based SCS protocols in reshaping the paradigms of data security.

Distinguishing itself from conventional methods, the protocol's unique approach employs vector variables for data block tagging, providing a leaner alternative to the resource-intensive matrix-variable techniques. Empirical evaluations have unequivocally showcased the protocol's diminished computational complexity, reaffirming its efficiency and scalability in real-world cloud storage scenarios.

The stringent security analysis conducted has not only validated the protocol's resilience against adversarial cloud entities but has also fortified its ability to safeguard data integrity. Furthermore, with provisions for accommodating dynamic data updates and batch auditing, the protocol's adaptability to the evolving landscape of data management within modern cloud environments further underscores its relevance.

In comparison to established lattice-based SCS protocols, our protocol's superior performance in operational efficiency and functional extensibility has been unequivocally demonstrated. These achievements collectively set the stage for agile and secure cloud storage solutions, poised to meet the distinctive challenges posed by the quantum advancements on the horizon.

In an era characterized by the continuous advancement of cloud computing and quantum technologies, this work serves as a launchpad for future exploration. The fusion of RLWE-based cryptography with secure cloud storage not only advances data security but also enriches the domains of post-quantum cryptography and secure cloud storage.

In conclusion, the significant strides made herein contribute not only to secure data outsourcing but also to broader domains of cryptography and cloud security. The protocol's potential to reshape data security in the ever-evolving landscape of cloud computing and quantum progress underscores our unwavering commitment to the pursuit of knowledge, as we endeavor to craft safer, more efficient data storage solutions for the future.

Future Exploration: The protocol's achievements propel future exploration at the nexus of cloud storage, quantum advancements, and data security, inviting continued research and innovation in the field.

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