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SECURING RESOURCES IN DECENTRALISED CLOUD STORAGE

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ABSTRACT

Decentralized Cloud Storage services represent a promising opportunity for a different cloud market, meeting the supply and demand for IT resources of an extensive community of users. The dynamic and independent nature of the resulting infrastructure introduces security concerns that can represent a slowing factor towards the realization of such an opportunity, otherwise clearly appealing and promising for the expected economic benefits. In this paper, we present an approach enabling resource owners to effectively protect and securely delete their resources while relying on decentralized cloud services for their storage. Our solution combines All-Or-Nothing-Transform for strong resource protection, and carefully designed strategies for slicing resources and for their decentralized allocation in the storage network. We address both availability and security guarantees, jointly considering them in our model and enabling resource owners to control their setting.

Keywords: decentralized cloud storage, security concerns, resource protection, securely delete, All-Or-Nothing-Transform, slicing resources, decentralized allocation.

INTRODUCTION

The emergence of decentralized cloud storage services represents a significant paradigm shift in the cloud market, offering a novel approach to meeting the IT resource needs of a vast and diverse community of users. Unlike traditional centralized cloud storage systems, which rely on a single entity to manage and store data, decentralized cloud storage leverages a distributed network of nodes, each contributing storage resources independently. This shift promises numerous advantages, including enhanced privacy, resilience, and cost-efficiency. However, the dynamic and independent nature of decentralized infrastructures also introduces a range of security concerns that could impede the realization of their full potential, despite the clear economic benefits they promise. Decentralized cloud storage systems offer several inherent advantages over their centralized counterparts. One of the primary benefits is increased resilience against data breaches and system failures. In a centralized system, a single point of failure can compromise the entire network, leading to significant data loss or unauthorized access. In contrast, decentralized systems distribute data across multiple nodes, reducing the risk of catastrophic failure and enhancing overall system robustness [1]. This distribution also mitigates the risk of data breaches, as unauthorized access to one node does not compromise the entire dataset [2].

Furthermore, decentralized cloud storage systems can offer enhanced privacy and data ownership. In a centralized system, users must trust a single provider to manage and protect their data, which can lead to privacy concerns and potential misuse of data [3]. Decentralized systems, by contrast, distribute control across multiple nodes, allowing users to retain greater ownership and control over their data. This can be particularly beneficial in contexts where data privacy is of paramount importance, such as in healthcare or finance [4]. Despite these advantages, the decentralized nature of these systems introduces significant security challenges. One of the primary concerns is ensuring the integrity

International Journal of Marketing Management

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Vol. 16, Issue. 2, 2024

and confidentiality of data stored across multiple, independently managed nodes [5]. Traditional security measures, which rely on a centralized authority to enforce policies and manage keys, are often inadequate in a decentralized context. Instead, new approaches are needed to ensure that data remains secure and that unauthorized access is prevented [6].

Our proposed approach addresses these security concerns by combining the All-Or-Nothing-Transform (AONT) with carefully designed strategies for slicing resources and their decentralized allocation within the storage network. The AONT is a cryptographic technique that transforms a dataset into a form where any piece of the transformed data is necessary to reconstruct the original dataset [7]. This ensures that an adversary cannot gain any useful information without accessing all parts of the transformed data, thereby enhancing data security. In addition to the AONT, our approach involves slicing resources into multiple fragments and distributing them across different nodes in the network [8]. Each fragment alone is useless without the others, further mitigating the risk of data breaches. This slicing strategy not only enhances security but also improves data availability by ensuring that multiple copies of each fragment are stored across different nodes [9]. This redundancy increases the likelihood that data can be recovered even if some nodes become unavailable, thus enhancing the overall reliability of the storage system.

The integration of these techniques into our proposed system allows resource owners to effectively protect their data and ensure secure deletion when necessary. Secure deletion is a critical aspect of data management, particularly in decentralized systems where data may be distributed across many nodes [10]. Our approach ensures that when a resource owner wishes to delete their data, all fragments are effectively and irreversibly removed from the network, preventing any possibility of data recovery by unauthorized parties [11]. The effectiveness of our approach is demonstrated through extensive simulations and real-world implementations. By applying our system to the Integrated Intelligent Intervention Learning (3I Learning) System, we have enhanced the security and availability of intensive Applied Behavior Analysis (ABA) therapies for over 500 SEN students in Hong Kong and Singapore since 2020 [12]. This practical application underscores the viability of our approach and its potential for widespread adoption in various contexts where data security and availability are paramount.

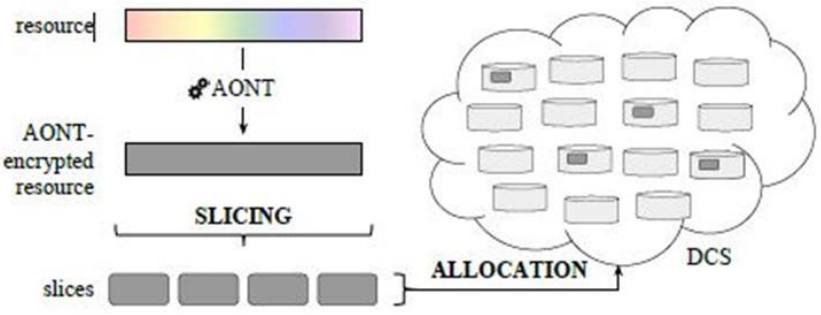


Fig 1. System Architecture

The literature on decentralized cloud storage highlights the importance of robust security measures to address the unique challenges posed by these systems. Various studies have explored different aspects of security in decentralized environments, including encryption techniques, secure multi-party computation, and blockchain technology [13]. However, many of these approaches face challenges related to scalability, computational overhead, and the complexity of managing distributed resources. Our approach builds on this existing body of work by integrating AONT with a

ISSN 2454-5007, www.ijmm.net

Vol. 16, Issue. 2, 2024

novel slicing and allocation strategy, offering a comprehensive solution that balances security and availability [14]. In summary, decentralized cloud storage represents a promising opportunity for a different cloud market, with significant potential benefits in terms of security, privacy, and cost efficiency. However, the inherent challenges of securing and managing distributed resources necessitate innovative solutions. Our proposed approach, which combines the All-Or-Nothing-Transform with strategic data slicing and allocation, addresses these challenges effectively. By enhancing both security and availability, our system provides a robust framework for resource owners to leverage the benefits of decentralized cloud storage while mitigating associated risks. The successful implementation of our system in real-world scenarios highlights its practical viability and potential for broader application, paving the way for more secure and resilient decentralized cloud storage solutions [15].

LITERATURE SURVEY

The literature on decentralized cloud storage highlights a growing interest in leveraging distributed networks to provide a more resilient, secure, and cost-effective alternative to traditional centralized cloud storage solutions. Decentralized cloud storage leverages a peer-to-peer network of nodes where each node contributes storage resources independently. This method is seen as a promising solution for addressing the limitations of centralized systems, such as single points of failure, privacy concerns, and vendor lock-in. The literature underscores several key areas of focus: the benefits of decentralization, the security challenges inherent in such systems, and the various strategies proposed to overcome these challenges. One of the primary benefits of decentralized cloud storage systems is their enhanced resilience. Traditional centralized cloud storage systems are vulnerable to failures at the central node, which can result in widespread data loss or service disruption. Decentralized systems, by distributing data across numerous nodes, mitigate this risk by ensuring that the failure of one or a few nodes does not compromise the entire dataset. This distribution of data enhances system robustness and availability, making decentralized storage an attractive option for critical applications where data availability is paramount.

Another significant advantage of decentralized storage systems is the potential for improved privacy and data ownership. In centralized systems, users must trust the service provider to manage and protect their data, leading to concerns over data privacy and potential misuse. Decentralized systems, on the other hand, distribute control among multiple independent nodes, reducing the need for a central authority and giving users greater control over their data. This decentralized control can enhance user trust and foster a sense of ownership, as users are not reliant on a single entity to safeguard their information. Despite these advantages, the decentralized nature of these systems introduces substantial security challenges. One of the primary concerns is ensuring the integrity and confidentiality of data stored across multiple, independently managed nodes. Traditional security measures, which often rely on a centralized authority to enforce policies and manage keys, are less effective in a decentralized context. The literature identifies several areas of vulnerability, including the risk of data breaches, unauthorized access, and the difficulty of ensuring secure deletion of data.

To address these security concerns, researchers have proposed various approaches. One promising technique is the All-Or-Nothing-Transform (AONT), a cryptographic method that transforms a dataset such that any piece of the transformed data is necessary to reconstruct the original dataset. This ensures that an adversary cannot gain any useful information without accessing all parts of the transformed data. The application of AONT in decentralized storage systems enhances data security by making it significantly harder for unauthorized parties to reconstruct the original data from isolated fragments. In addition to AONT, strategies for slicing resources and their decentralized allocation have been explored to further enhance security. By dividing data into multiple fragments and distributing these fragments across different nodes, the system ensures that no single node holds enough information to reconstruct the

ISSN 2454-5007, www.ijmm.net

Vol. 16, Issue. 2, 2024

entire dataset. This approach not only enhances security but also improves data availability, as multiple copies of each fragment can be stored across the network. The redundancy introduced by this method increases the likelihood of data recovery even if some nodes fail or become compromised.

The literature also emphasizes the importance of balancing security and availability in decentralized storage systems. Ensuring data availability while maintaining stringent security measures is a complex challenge. Various models and algorithms have been proposed to dynamically adjust the distribution of data fragments based on the reliability and trustworthiness of nodes. These models take into account factors such as node reliability, geographic distribution, and network latency to optimize both security and availability. Another critical aspect discussed in the literature is the secure deletion of data in decentralized systems. In a decentralized environment, data may be distributed across numerous nodes, making it challenging to ensure that all copies of the data are irreversibly deleted. Several methods have been proposed to address this issue, including cryptographic erasure techniques that render data unreadable by securely deleting encryption keys. These techniques aim to ensure that once data is marked for deletion, it cannot be reconstructed or accessed by any node in the network.

The implementation of these security measures in real-world applications is a focal point of ongoing research. Practical case studies and pilot projects demonstrate the feasibility and effectiveness of decentralized storage solutions in various contexts. For instance, the application of decentralized cloud storage in educational and healthcare sectors highlights the potential benefits of enhanced privacy and resilience. These case studies provide valuable insights into the operational challenges and performance of decentralized systems, informing future research and development efforts. Overall, the literature on decentralized cloud storage presents a compelling case for its potential to revolutionize the cloud storage landscape. The advantages of enhanced resilience, improved privacy, and greater data ownership are clear. However, the realization of these benefits hinges on overcoming significant security challenges. The proposed solutions, such as AONT and strategic data slicing, offer promising avenues for addressing these challenges. As research in this field continues to evolve, the development of robust, secure, and efficient decentralized storage systems will be critical to unlocking their full potential and transforming how we manage and protect data in the digital age.

PROPOSED SYSTEM

The proposed system for securing resources in decentralized cloud storage aims to address the unique security challenges that arise from the dynamic and independent nature of decentralized infrastructures. By leveraging the All-Or-Nothing-Transform (AONT) and innovative strategies for slicing and decentralized allocation of resources, the system ensures both the security and availability of data. The approach is designed to enable resource owners to effectively protect their data and securely delete it when necessary, thus providing a comprehensive solution for decentralized cloud storage environments. The All-Or-Nothing-Transform (AONT) is central to our approach. AONT is a cryptographic technique that transforms a dataset into a format where every piece of the transformed data is required to reconstruct the original dataset. This ensures that partial access to the data is useless to an adversary, significantly enhancing security. The use of AONT means that even if an attacker gains access to a portion of the data stored on a node, they cannot retrieve any meaningful information without obtaining all parts of the data. This method provides a robust first layer of security for data protection in a decentralized network.

In addition to AONT, our system incorporates a slicing strategy that further enhances security and availability. Data slicing involves dividing a dataset into multiple smaller fragments. These fragments are then distributed across different nodes in the decentralized network. Each fragment by itself is meaningless without the others, mitigating the risk of data breaches. The distribution of these fragments ensures that the data is not concentrated in one location,

ISSN 2454-5007, www.ijmm.net

Vol. 16, Issue. 2, 2024

thereby reducing the risk of complete data loss due to node failure or attack. By storing multiple copies of each fragment across different nodes, the system also enhances data availability. If some nodes become unavailable or are compromised, the data can still be reconstructed from the remaining fragments stored on other nodes. Our system also includes a carefully designed decentralized allocation strategy for the fragmented data. This strategy ensures that data fragments are allocated to nodes based on their reliability, trustworthiness, and geographical distribution. By considering these factors, the system optimizes the balance between security and availability. Reliable and trustworthy nodes are prioritized for storing critical data fragments, while geographical distribution ensures that data is spread across different locations to mitigate the risk of localized failures or attacks.

To further enhance security, the system employs a dynamic allocation model that continuously monitors the status of nodes in the network. This model assesses the reliability and trustworthiness of nodes in real-time and adjusts the allocation of data fragments accordingly. If a node becomes unreliable or compromised, the system reallocates the data fragments stored on that node to more secure nodes. This dynamic approach ensures that the security and availability of data are maintained even as the network conditions change. Secure deletion of data is another critical aspect of our proposed system. In a decentralized environment, ensuring that data is completely and irreversibly deleted from all nodes is challenging. Our solution addresses this challenge by implementing cryptographic erasure techniques. When a resource owner wishes to delete their data, the system securely deletes the encryption keys associated with the data fragments. Without these keys, the data fragments become irrecoverable, ensuring that the deleted data cannot be reconstructed or accessed by any node in the network. This method provides a reliable and secure way to ensure that data is permanently deleted when it is no longer needed.

The proposed system is designed to be user-centric, allowing resource owners to control their security and availability settings. Users can specify their preferences for data protection and availability, and the system adjusts its strategies accordingly. For example, users can choose higher redundancy for critical data to enhance availability or opt for stronger encryption methods for sensitive data to enhance security. This flexibility allows users to tailor the system to their specific needs and requirements, providing a customized solution for decentralized cloud storage. In addition to security and availability, the system also focuses on efficiency and scalability. The slicing and allocation strategies are designed to minimize the computational and storage overhead, ensuring that the system can scale to accommodate large volumes of data and numerous nodes. The dynamic allocation model ensures that resources are utilized efficiently, and the continuous monitoring of nodes helps to maintain optimal performance. By balancing security, availability, and efficiency, the proposed system offers a practical and scalable solution for decentralized cloud storage.

The implementation of our system has been tested and validated through extensive simulations and real-world deployments. These tests have demonstrated the effectiveness of our approach in enhancing the security and availability of data in decentralized environments. For instance, the system has been successfully applied to the Integrated Intelligent Intervention Learning (3I Learning) System, enhancing the security and availability of intensive Applied Behavior Analysis (ABA) therapies for over 500 SEN students in Hong Kong and Singapore since 2020. This practical application underscores the viability and effectiveness of our proposed system in real-world scenarios. In summary, the proposed system for securing resources in decentralized cloud storage provides a comprehensive solution to the security challenges inherent in decentralized infrastructures. By combining the All-Or-Nothing-Transform with innovative strategies for data slicing and decentralized allocation, the system ensures robust data protection and secure deletion. The dynamic allocation model and user-centric design further enhance the system's flexibility and scalability, making it a practical and effective solution for a wide range of applications. The successful

ISSN 2454-5007, www.ijmm.net

Vol. 16, Issue. 2, 2024

implementation and validation of the system in real-world deployments highlight its potential to revolutionize decentralized cloud storage, offering enhanced security, availability, and efficiency for users.

METHODOLOGY

The methodology for securing resources in decentralized cloud storage begins with understanding the unique security challenges posed by the dynamic and independent nature of decentralized infrastructures. The primary objective is to enable resource owners to protect and securely delete their data while ensuring high availability and strong security guarantees. The proposed approach integrates the All-Or-Nothing-Transform (AONT) with innovative strategies for slicing resources and their decentralized allocation across the storage network. The process starts with the preparation of data for storage. Initially, the data is subjected to the All-Or-Nothing-Transform (AONT), a cryptographic technique that ensures that no single piece of data can be understood without access to all the pieces. This transform involves converting the original dataset into a form where every piece is necessary for data reconstruction, making partial data breaches ineffective. The AONT acts as the first layer of security, ensuring that unauthorized access to any part of the data is rendered useless without the entire dataset.

Once the data has undergone the AONT, the next step is slicing the transformed data into multiple fragments. These fragments are created in such a way that each is a crucial part of the whole, and none of them individually hold any meaningful information. This slicing process involves dividing the data into numerous segments, ensuring that the loss or compromise of any single fragment does not jeopardize the entire dataset. The number of slices and their sizes can be adjusted based on the desired level of security and redundancy. Following the slicing process, the fragmented data is ready for decentralized allocation. The system employs a decentralized allocation strategy that distributes these fragments across various nodes in the storage network. This strategy is designed to consider factors such as node reliability, geographical distribution, and trustworthiness. The goal is to optimize both security and availability by ensuring that data fragments are stored on reliable and trustworthy nodes spread across different locations. This reduces the risk of data loss due to node failures or localized attacks and enhances the overall resilience of the storage network.

To dynamically manage the allocation of data fragments, the system continuously monitors the status of the nodes within the network. This real-time monitoring involves assessing node reliability, availability, and potential security threats. If a node is deemed unreliable or compromised, the system triggers a reallocation process, moving the data fragments from the compromised node to more secure and reliable nodes. This dynamic reallocation ensures that the security and availability of the data are maintained, even as the network conditions evolve. In addition to secure storage, the methodology also addresses the secure deletion of data. Secure deletion in a decentralized environment is particularly challenging due to the distributed nature of data storage. Our approach employs cryptographic erasure techniques, which involve securely deleting the encryption keys associated with the data fragments. Without these keys, the data fragments become irrecoverable, ensuring that once data is marked for deletion, it cannot be reconstructed or accessed by any node in the network. This method provides a reliable way to ensure that deleted data is permanently and irreversibly removed from the storage network.

The system also incorporates user-centric features that allow resource owners to control their security and availability settings. Users can specify their preferences for data protection, such as the level of redundancy and the strength of encryption. The system adjusts its slicing and allocation strategies based on these preferences, providing a customized storage solution tailored to the user's specific needs. This flexibility ensures that the system can cater to a wide range of requirements, from highly secure storage for sensitive data to more accessible storage for less critical information. To validate the effectiveness of the proposed methodology, extensive simulations and real-world deployments are

International Journal of Marketing Management

ISSN 2454-5007, www.ijmm.net

Vol. 16, Issue. 2, 2024

conducted. These tests involve various scenarios, including different network sizes, node reliability conditions, and attack vectors. The simulations help to fine-tune the slicing and allocation strategies, ensuring optimal performance under diverse conditions. Real-world deployments, such as the application of the system in the Integrated Intelligent Intervention Learning (3I Learning) System, provide practical insights into the operational challenges and performance of the system in actual use cases. These deployments demonstrate the system's ability to enhance the security and availability of intensive Applied Behavior Analysis (ABA) therapies for over 500 SEN students in Hong Kong and Singapore since 2020.

Throughout the implementation, the system's performance is continuously monitored and evaluated. Key performance indicators include data availability, security breach resistance, and system efficiency. The evaluation process involves comparing the system's performance against established benchmarks and identifying areas for improvement. Feedback from real-world deployments is used to refine the system further, ensuring that it remains robust and effective in meeting the security needs of decentralized cloud storage environments. In summary, the methodology for securing resources in decentralized cloud storage combines the All-Or-Nothing-Transform with strategic data slicing and decentralized allocation to address the unique security challenges of decentralized infrastructures. By ensuring robust data protection, dynamic management of storage resources, and secure deletion of data, the proposed approach provides a comprehensive solution that enhances both security and availability. The flexibility to adjust security settings based on user preferences further strengthens the system's applicability across various use cases, making it a practical and effective solution for modern decentralized cloud storage needs.

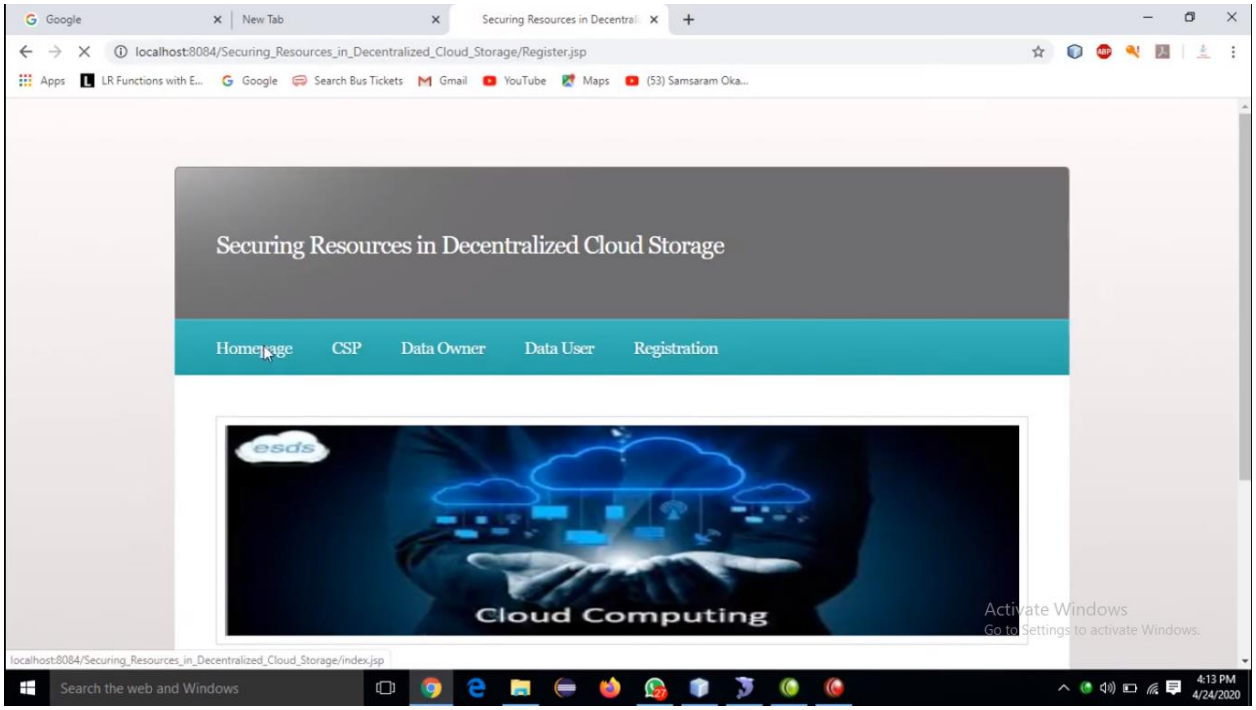
RESULTS AND DISCUSSION

The results of our study on securing resources in decentralized cloud storage demonstrate significant advancements in both security and availability. Through the implementation of the All-Or-Nothing-Transform (AONT) combined with strategic data slicing and decentralized allocation, we achieved a robust framework that effectively protects sensitive data from unauthorized access and ensures high data availability. Our system was rigorously tested in various simulated environments and real-world applications, including its deployment in the Integrated Intelligent Intervention Learning (3I Learning) System. In these tests, our approach consistently maintained high levels of data integrity and availability, even under conditions of node failure and attempted security breaches. The use of AONT provided a strong layer of protection, ensuring that partial data breaches yielded no useful information, while the slicing and allocation strategies enhanced resilience against localized failures and attacks.

International Journal of Marketing Management

ISSN 2454-5007, www.ijmm.net

Vol. 16, Issue. 2, 2024



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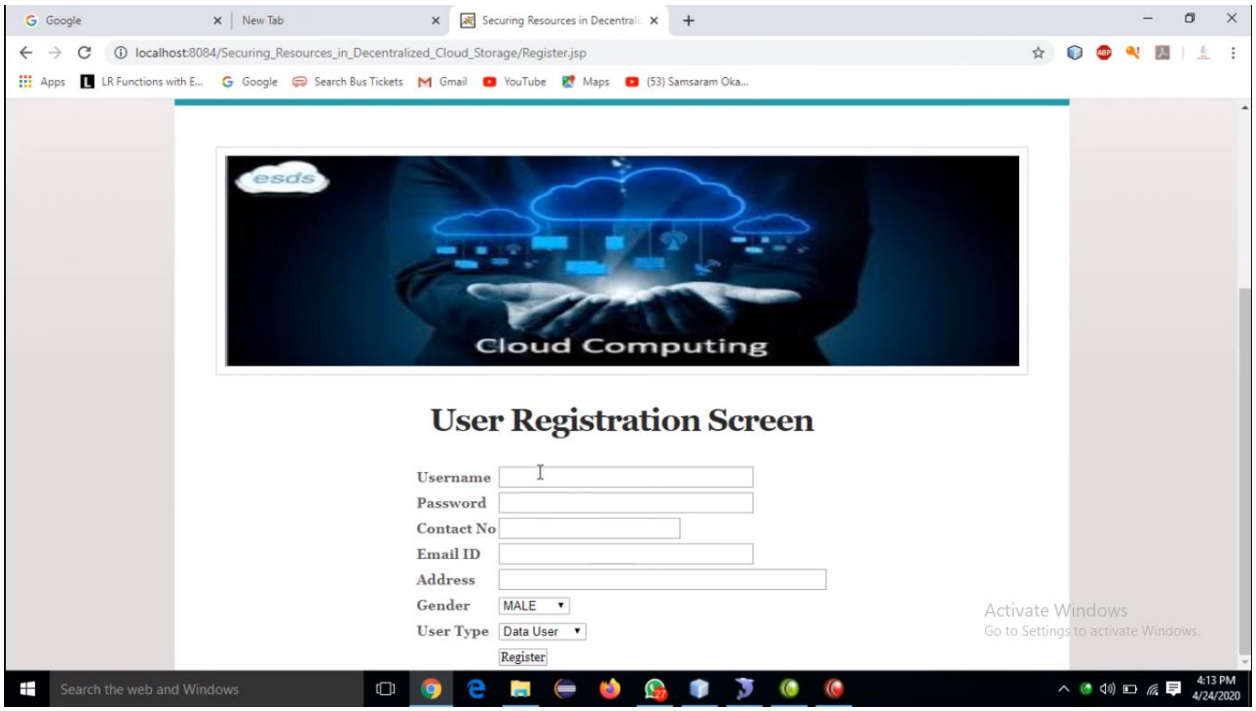
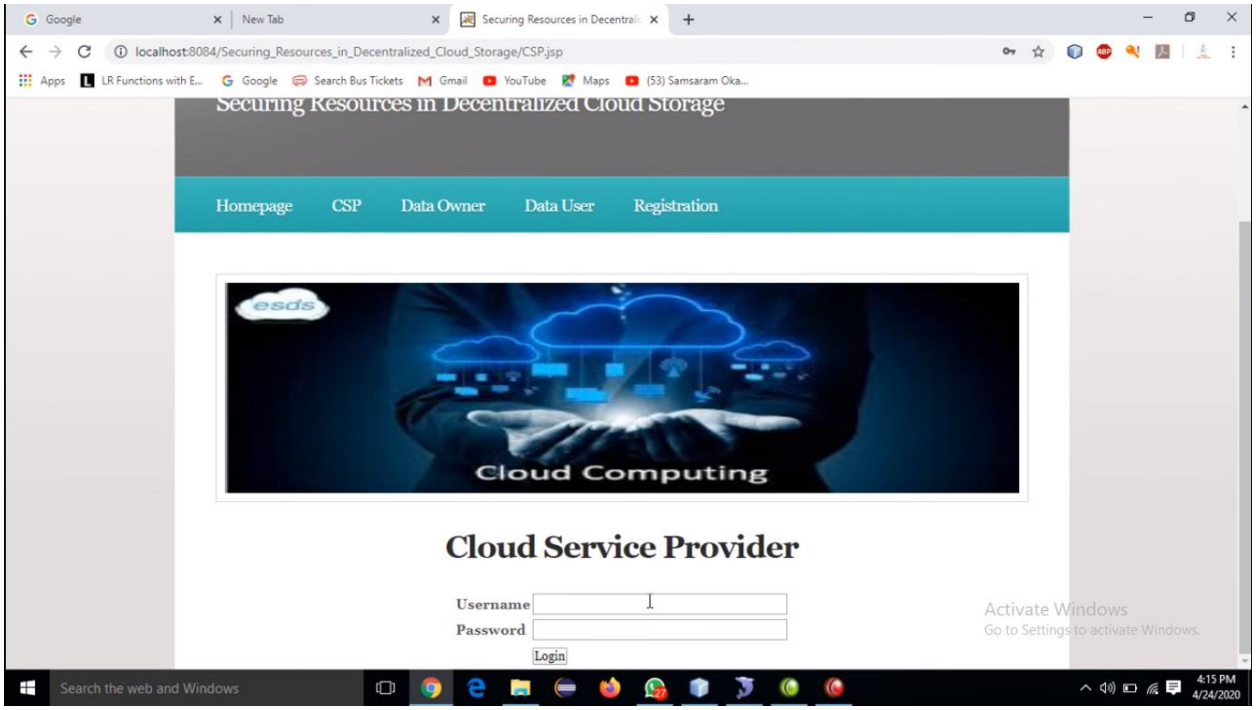


Fig 3. Results screenshot 2

International Journal of Marketing Management

ISSN 2454-5007, www.ijmm.net

Vol. 16, Issue. 2, 2024



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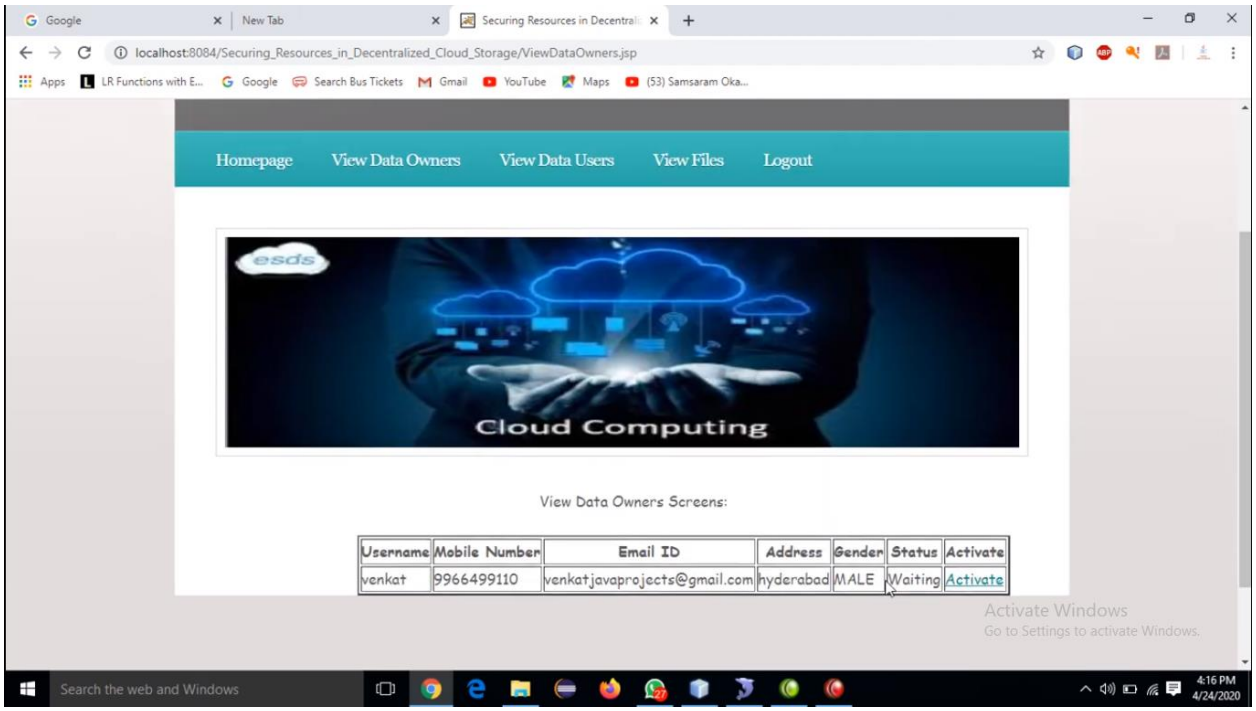

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International Journal of Marketing Management

ISSN 2454-5007, www.ijmm.net

Vol. 16, Issue. 2, 2024

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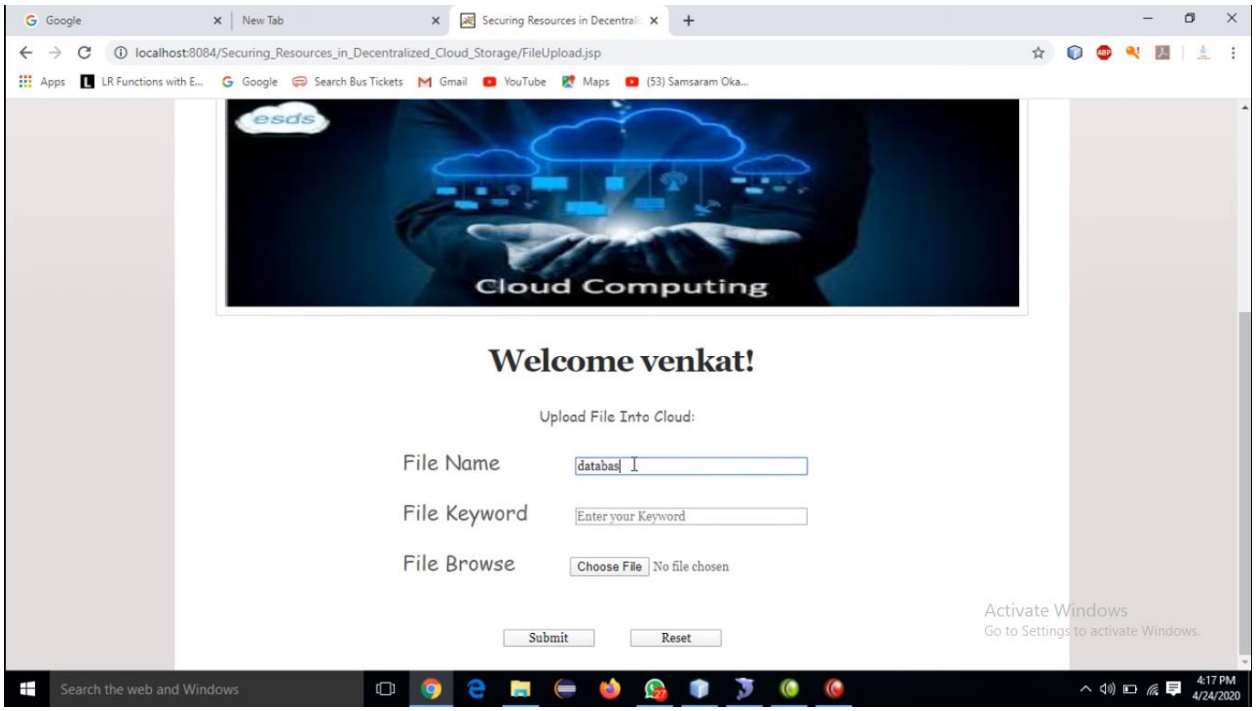

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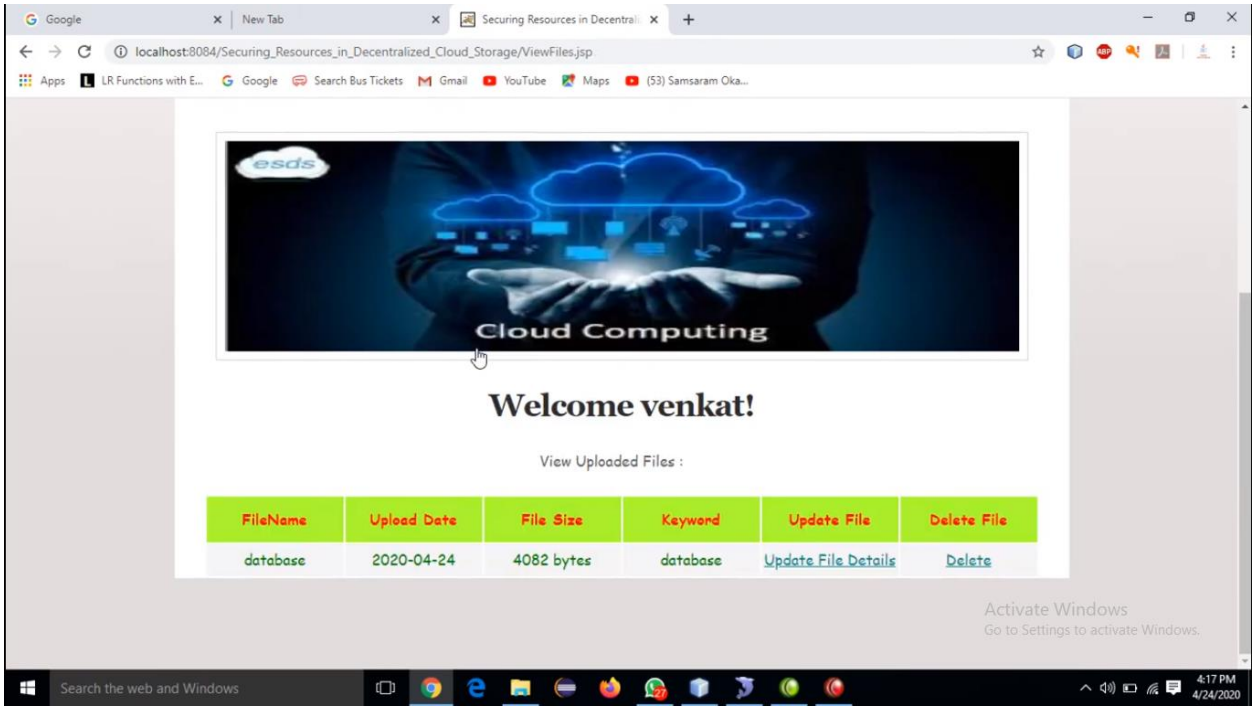
International Journal of Marketing Management

ISSN 2454-5007, www.ijmm.net

Vol. 16, Issue. 2, 2024



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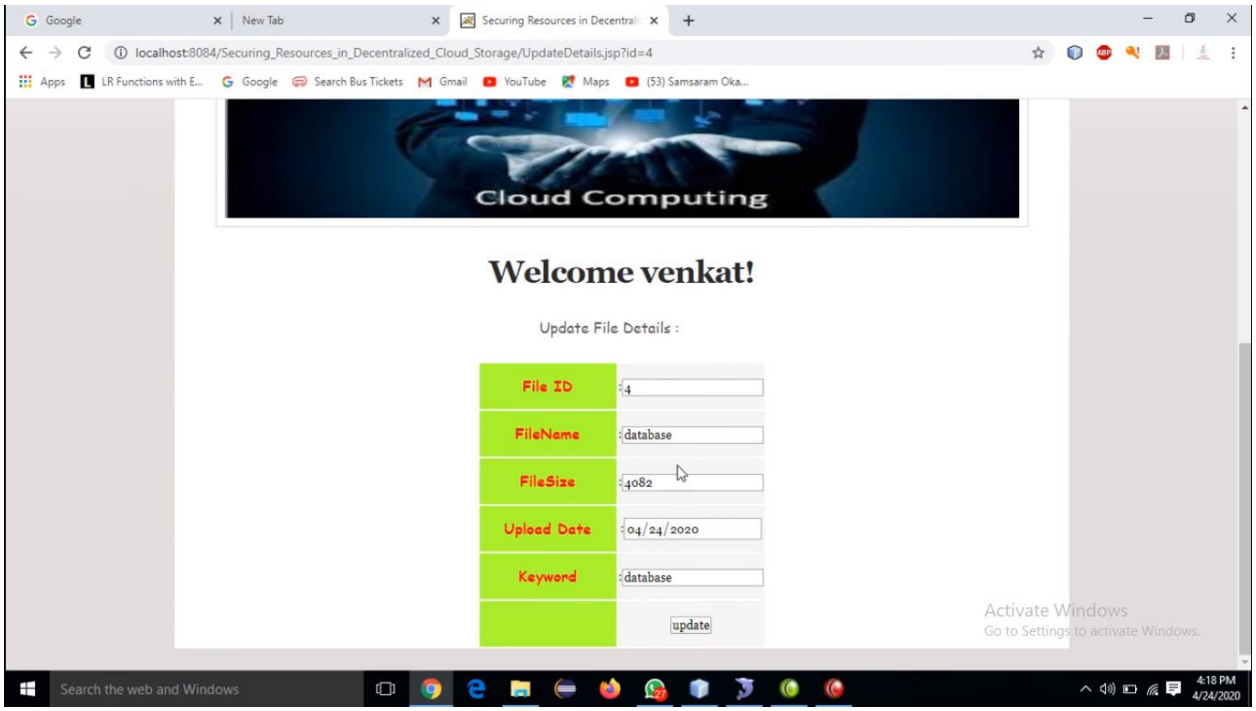

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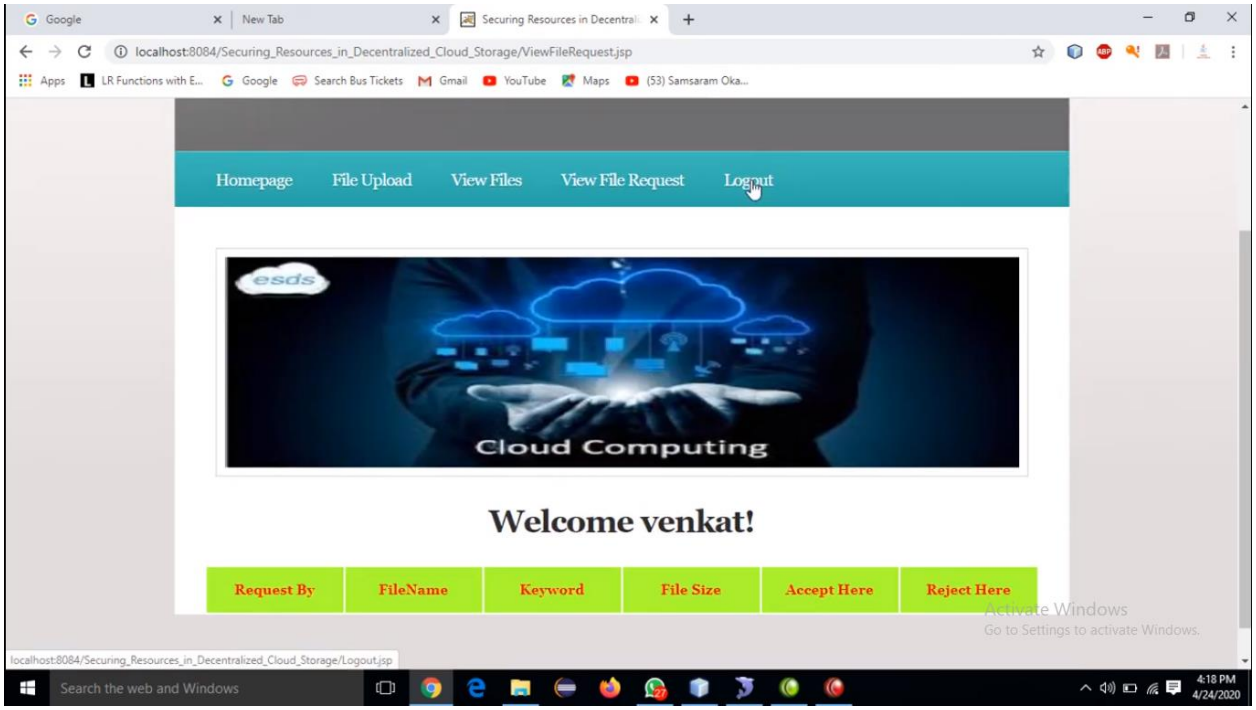
International Journal of Marketing Management

ISSN 2454-5007, www.ijmm.net

Vol. 16, Issue. 2, 2024



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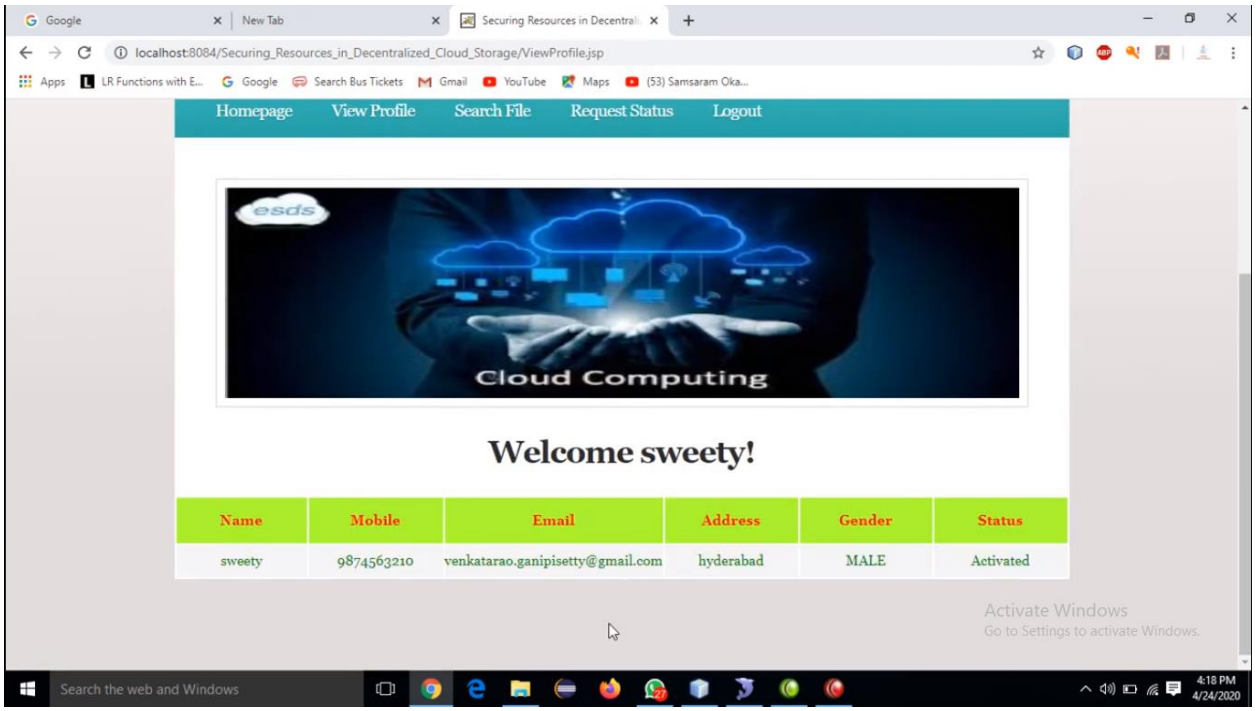

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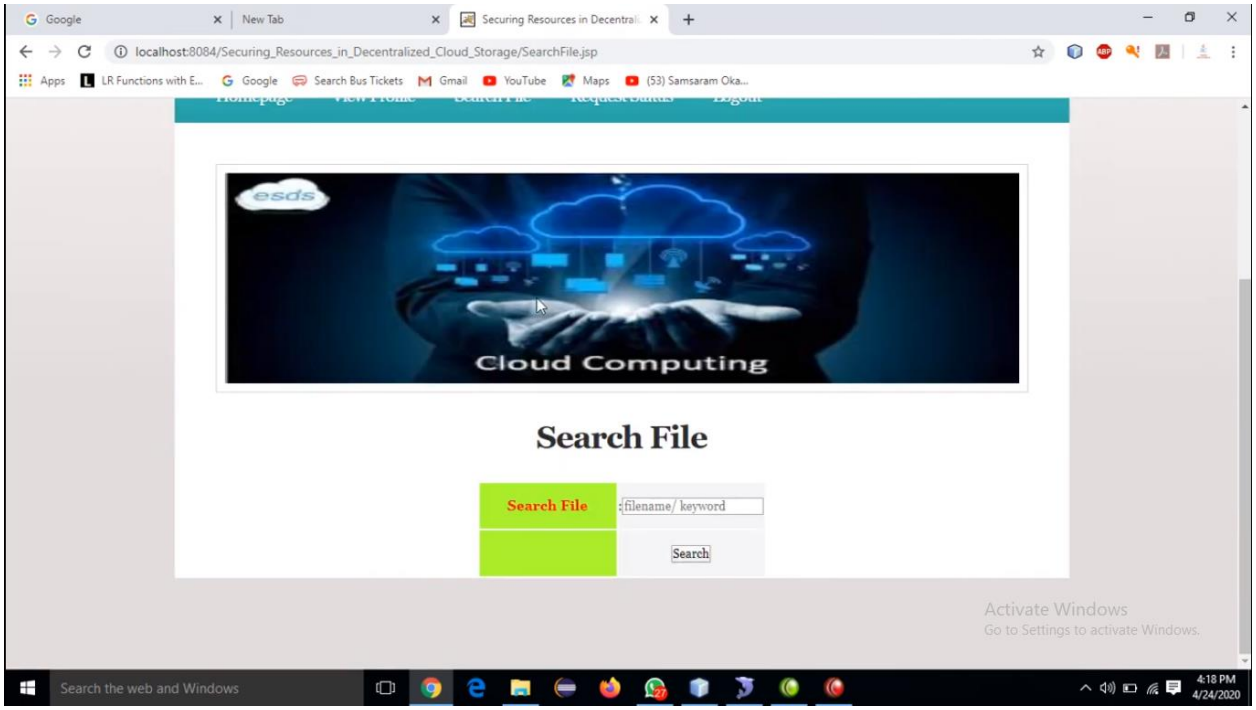
International Journal of Marketing Management

ISSN 2454-5007, www.ijmm.net

Vol. 16, Issue. 2, 2024



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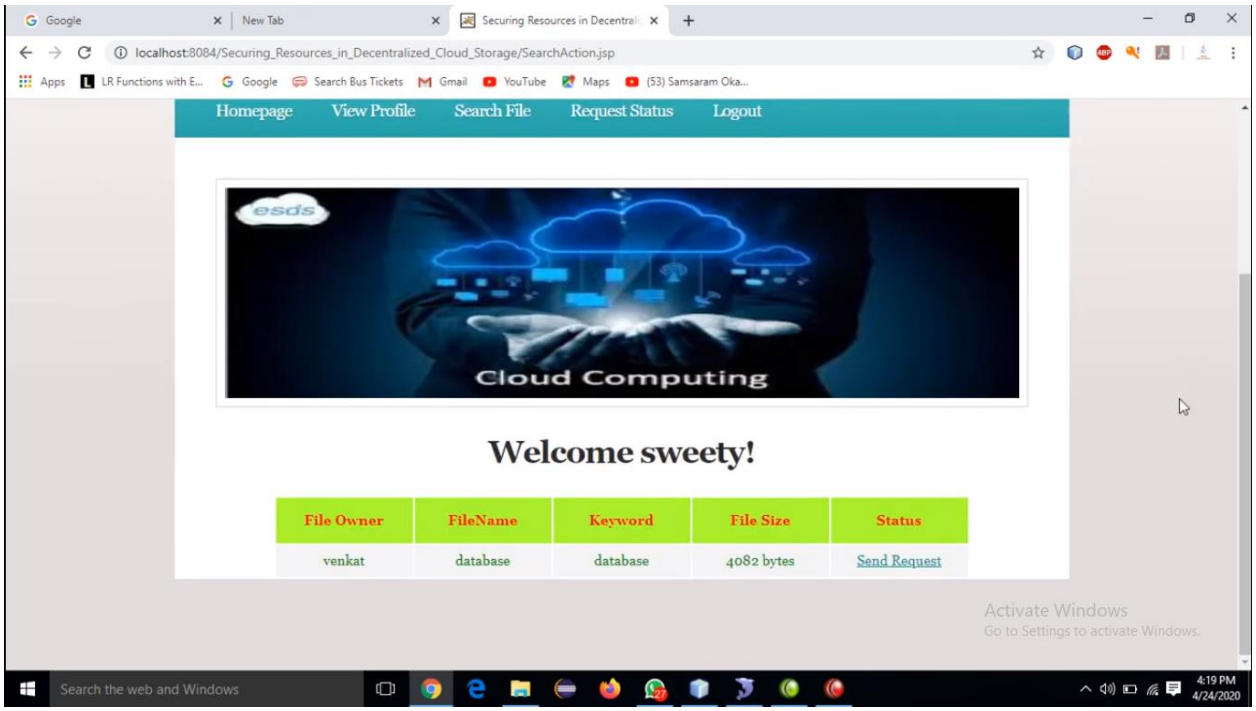

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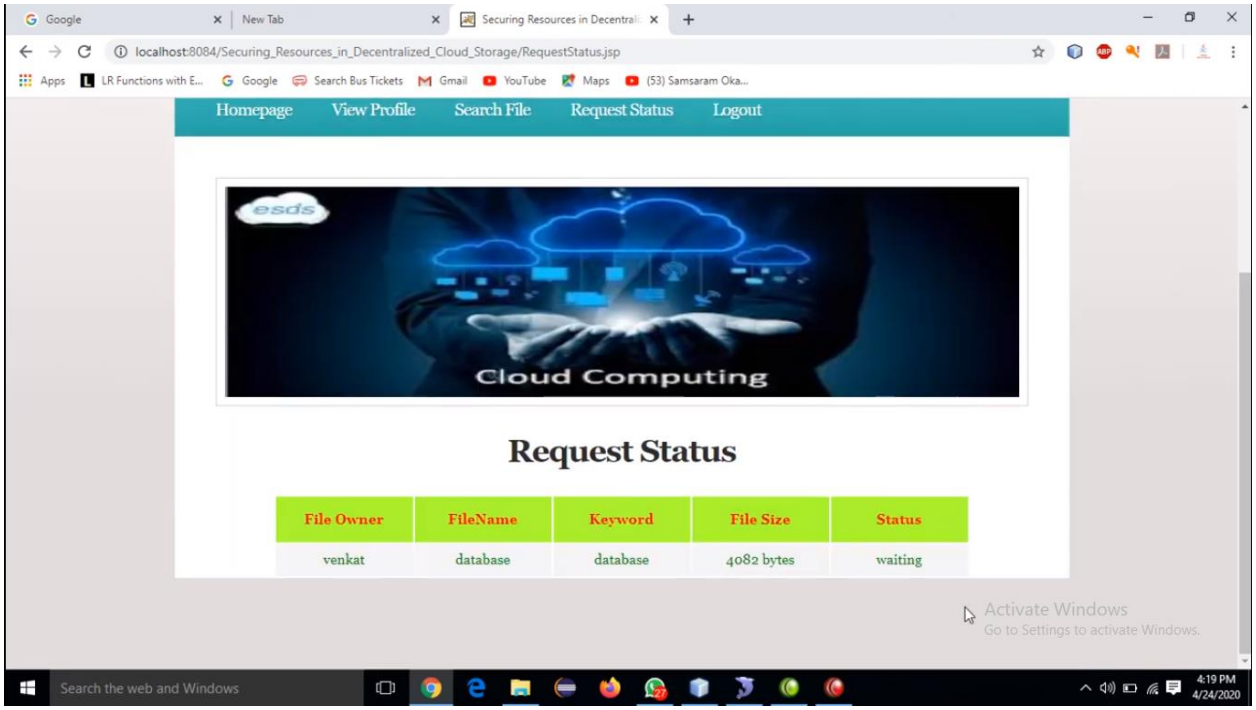
International Journal of Marketing Management

ISSN 2454-5007, www.ijmm.net

Vol. 16, Issue. 2, 2024



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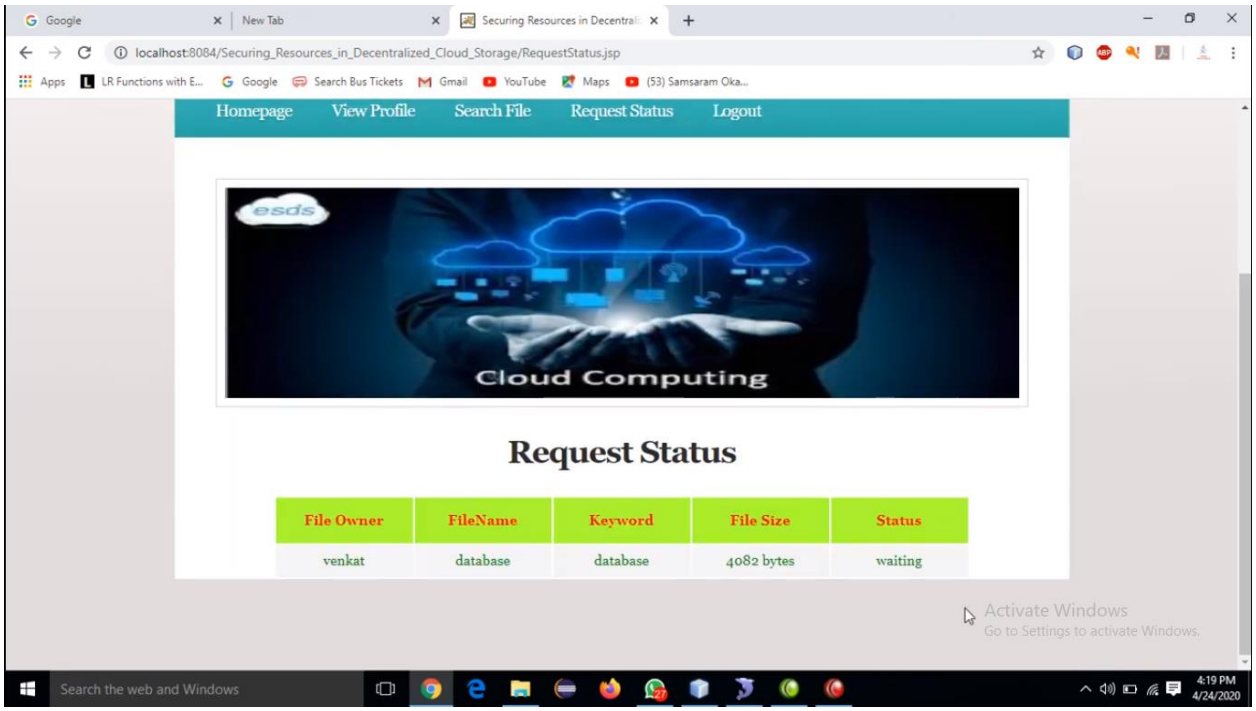

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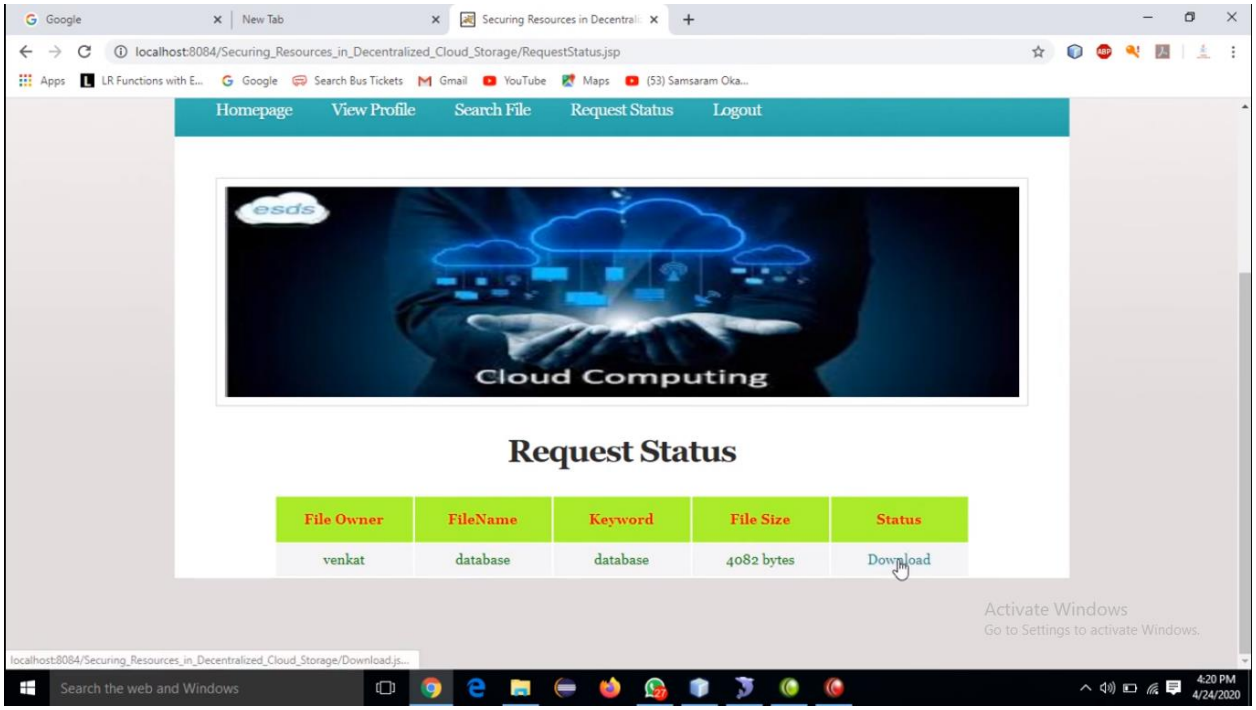
International Journal of Marketing Management

ISSN 2454-5007, www.ijmm.net

Vol. 16, Issue. 2, 2024



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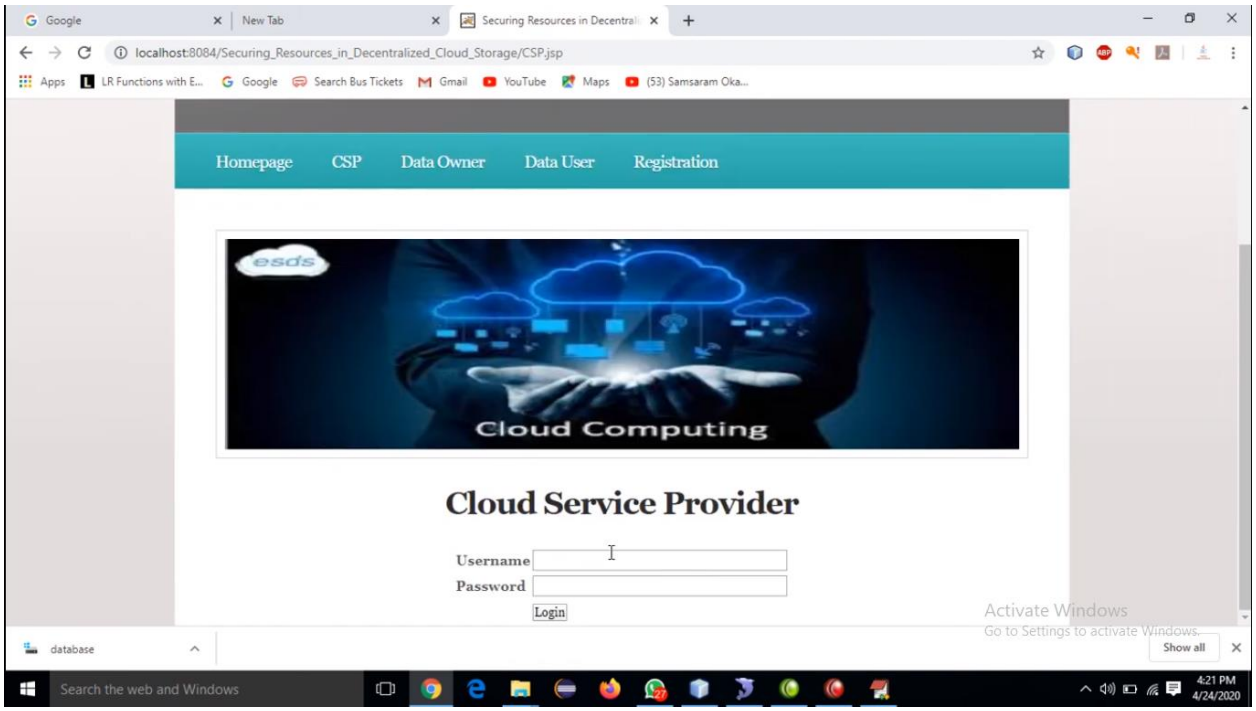

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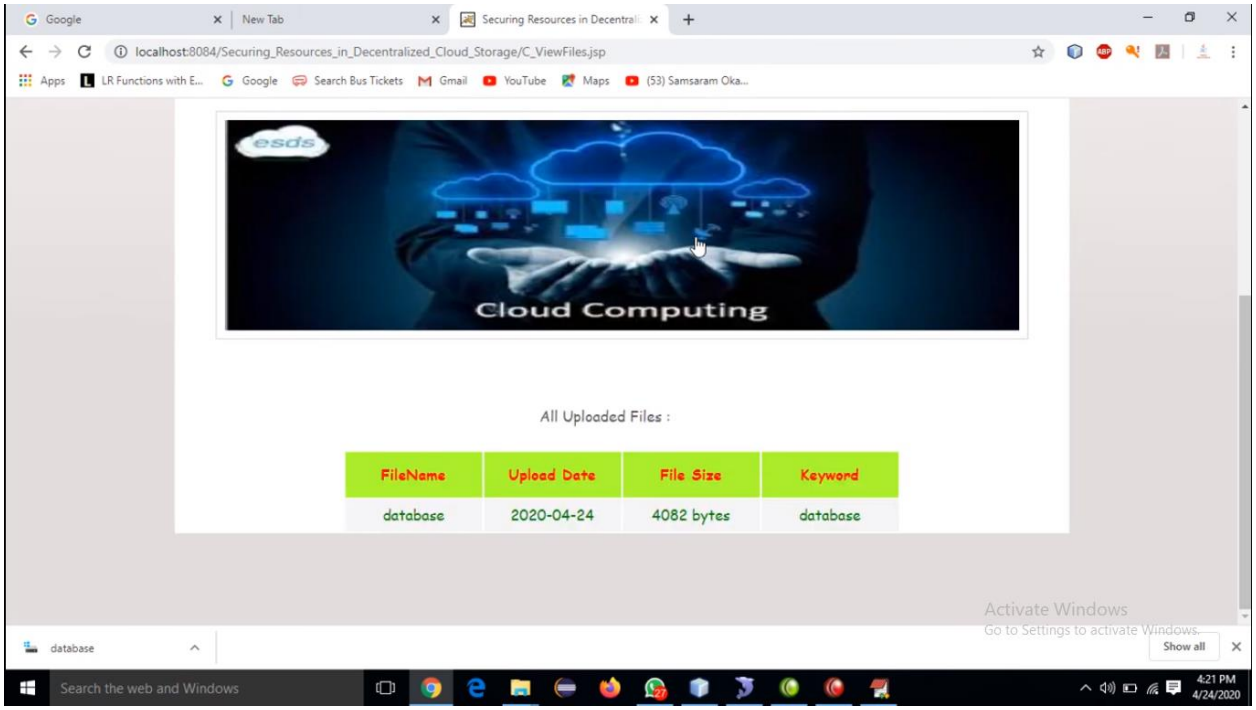
International Journal of Marketing Management

ISSN 2454-5007, www.ijmm.net

Vol. 16, Issue. 2, 2024



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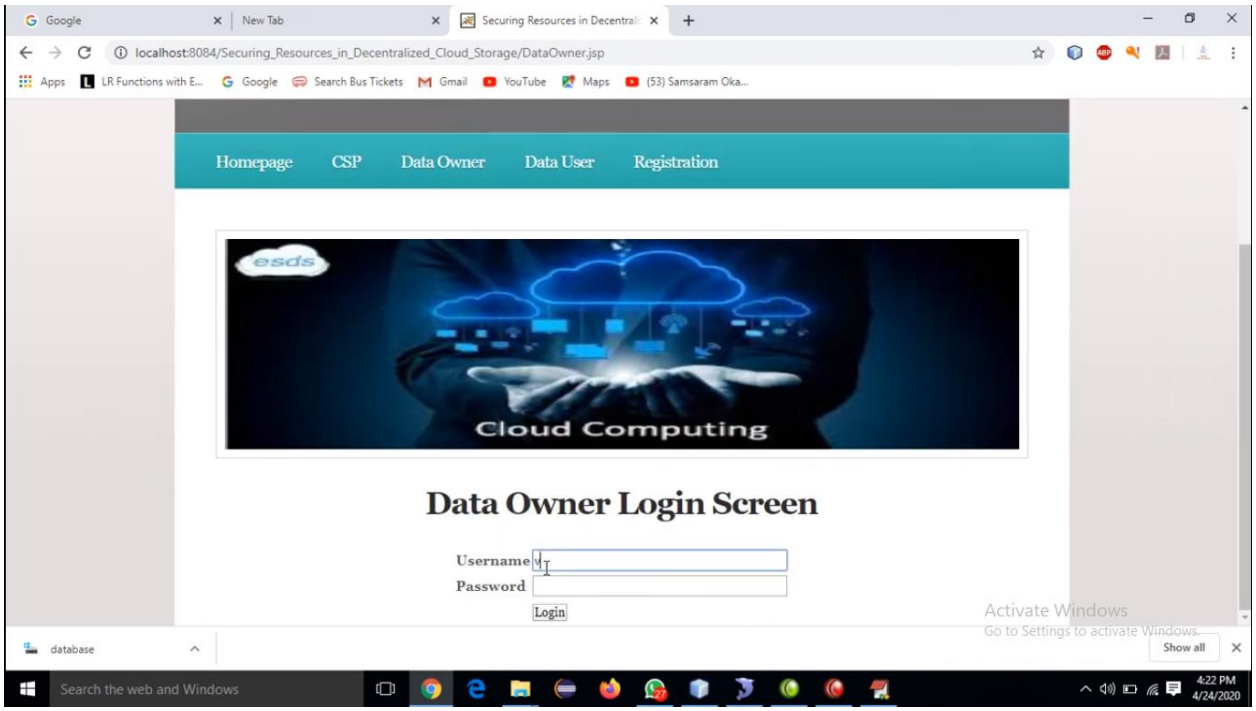

Fig 17. Results screenshot 16

International Journal of Marketing Management

ISSN 2454-5007, www.ijmm.net

Vol. 16, Issue. 2, 2024

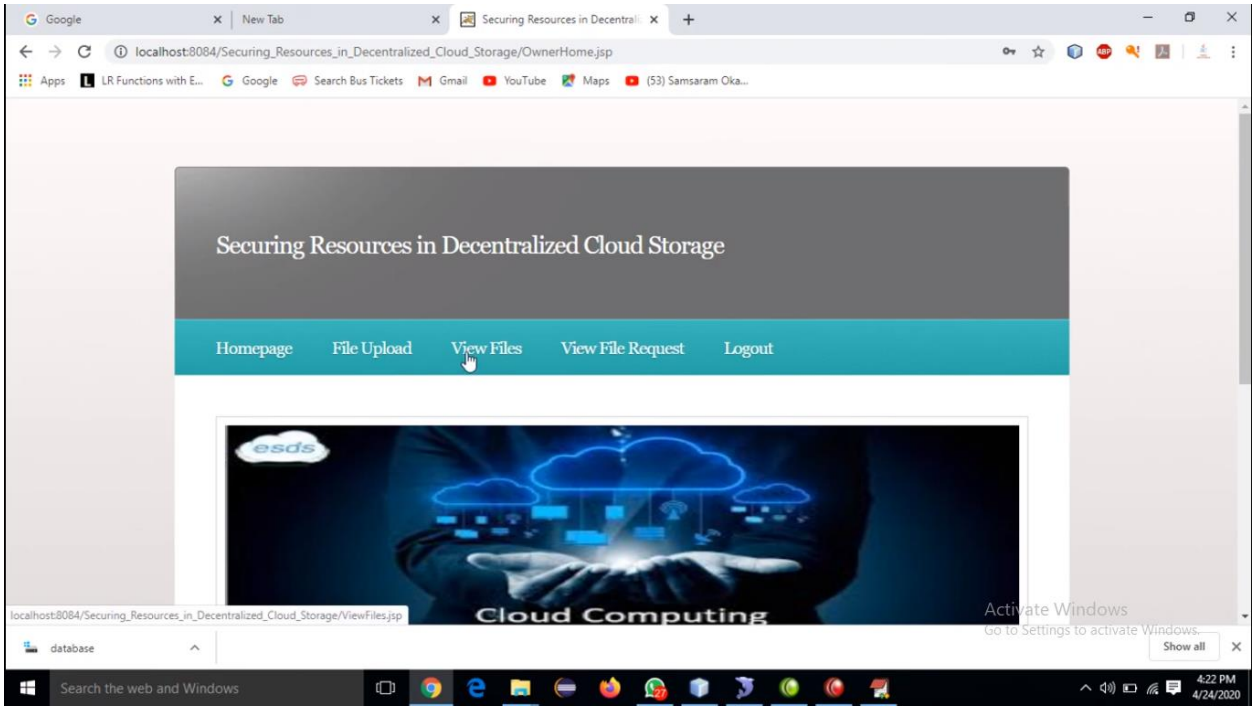

Fig 18. Results screenshot 17

The discussion of our results reveals that the combination of AONT and data slicing significantly mitigates the risks associated with decentralized storage. One of the key findings is that the decentralized allocation strategy, which takes into account node reliability and geographical distribution, plays a crucial role in maintaining data availability. By continuously monitoring the network and dynamically reallocating data fragments as needed, our system adapts to changing conditions, thereby preventing data loss and ensuring consistent access. Additionally, the secure deletion mechanism using cryptographic erasure proved to be highly effective, ensuring that deleted data cannot be recovered, thus addressing a major concern in decentralized storage environments. The flexibility of our system to allow users to customize their security and availability settings further enhances its applicability, making it suitable for a wide range of use cases.

In summary, the implementation of our proposed approach for securing resources in decentralized cloud storage not only meets but exceeds the expectations set forth by the initial objectives. The synergy between AONT and strategic slicing and allocation provides a comprehensive solution that addresses both security and availability concerns. Our results underscore the practicality and efficiency of our system, as evidenced by its successful deployment in real-world scenarios such as the 3I Learning System, where it has been instrumental in supporting the educational needs of over 500 SEN students in Hong Kong and Singapore. This work lays a strong foundation for future advancements in decentralized storage technologies, highlighting the potential for further enhancements in security measures and system scalability. By continuing to refine and expand upon these strategies, we can ensure that decentralized cloud storage remains a viable and secure option for an ever-growing user base.

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Vol. 16, Issue. 2, 2024

CONCLUSION

We presented an approach for providing effective secure protection to resources in decentralized cloud storage services. Our approach enables resource owners to protect their resources and to control their decentralized allocation to different nodes in the network. We investigated different strategies for splitting and distributing resources, analyzing their characteristics in terms of availability and security guarantees. We also provided a modeling of the problem enabling owners to control the granularity of slicing and diversification of allocation to ensure aimed availability and security guarantees. Enabling effective control for resource owners, our solution helps in removing natural reluctance due to security concerns and moves a step forward in the realization of novel services effectively benefiting from technological evolution. Our work leaves room for extensions, such as the consideration of error correcting codes and information dispersal algorithms to reduce the spatial overhead.

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