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Secure Healthcare Access Control System (SHACS) for Anomaly Detection and Enhanced Security in Cloud-Based Healthcare Applications

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ABSTRACT

The rapid adoption of cloud-based healthcare systems has intensified the need for secure, efficient, and adaptive access control mechanisms to protect sensitive Electronic Health Records (EHRs). This study presents an enhanced implementation of the Secure Healthcare Access Control System (SHACS), integrating a hybrid access control model with practical system deployment using Java-based architecture. Unlike traditional approaches that rely solely on Role-Based Access Control (RBAC) or Attribute-Based Access Control (ABAC), the proposed system combines both models with dynamic rule enforcement to enable fine-grained and context-aware authorization.

The framework incorporates multi-factor authentication, secure key exchange, and advanced encryption techniques to ensure data confidentiality during transmission and storage. Additionally, a real-time anomaly detection module analyzes user behavior patterns to identify and mitigate unauthorized access attempts proactively. The system is further strengthened through audit logging, data masking, and continuous monitoring, enhancing transparency and compliance with healthcare data protection standards.

Experimental evaluation demonstrates improved authentication efficiency, reduced access latency, and enhanced scalability compared to conventional models. By providing a practical and deployable solution, the proposed system bridges the gap between theoretical security frameworks and real-world healthcare applications, ensuring robust protection of medical data while maintaining operational efficiency.

Index Terms— Healthcare access control, cloud security, electronic health records (EHR), role-based access control (RBAC), attribute-based access control (ABAC), anomaly detection, multi-factor authentication (MFA), data privacy, encryption, secure data sharing, intrusion detection, healthcare cybersecurity, access control policies, audit logging, data protection.

I. INTRODUCTION

Cloud computing has significantly transformed the healthcare sector by enabling efficient storage, management, and sharing of Electronic Health Records (EHRs). The integration of cloud-based platforms allows healthcare providers to access patient data remotely, improving decision-making, collaboration, and overall patient care. However, this digital transformation introduces critical challenges related to data privacy, security, and access control. Sensitive healthcare information, including medical history, diagnostic reports, and real-time monitoring data, is highly vulnerable to unauthorized access, cyberattacks, and data breaches, making robust security mechanisms essential [1], [2].

Traditional access control mechanisms such as Role-Based Access Control (RBAC) and Attribute-Based Access Control (ABAC) have been widely used in healthcare systems. RBAC assigns permissions based on predefined roles, simplifying management but lacking flexibility in dynamic environments. On the other hand, ABAC provides fine-grained control by considering multiple attributes such as user role, resource type, and environmental conditions. Despite its flexibility, ABAC introduces complexity in policy management and may lead to increased computational overhead and access delays [3]–[5]. These limitations highlight the need for more adaptive and efficient access control models.

Recent advancements have focused on hybrid models that combine RBAC and ABAC with rule-based policies to achieve both flexibility and efficiency. These models aim to dynamically adjust access permissions based on contextual factors, thereby improving security without compromising system performance. Additionally, the integration of machine learning techniques has enabled the development of intelligent systems capable of detecting anomalous access patterns and preventing potential security threats in real time [6]–[9].

The increasing adoption of cloud-based healthcare systems also demands compliance with regulatory standards such as HIPAA and GDPR, which enforce strict requirements on data protection and access control. Ensuring compliance while maintaining system efficiency remains a major challenge for healthcare organizations [10]. Moreover, the growing volume of healthcare data necessitates scalable solutions that can handle high workloads without degrading performance.

To address these challenges, the Secure Healthcare Access Control System (SHACS) was introduced as an advanced framework that integrates role-based and attribute-based access control with dynamic rule

enforcement and anomaly detection. While SHACS demonstrates significant improvements in authentication efficiency, access delay reduction, and security enhancement, its practical implementation and real-world deployment require further exploration.

In this work, we propose an enhanced and implementable version of SHACS using a Java-based architecture, incorporating multi-factor authentication, encryption, audit logging, and real-time anomaly detection. The proposed system aims to bridge the gap between theoretical models and practical applications by providing a scalable, secure, and efficient access control mechanism for cloud-based healthcare environments. This approach not only strengthens data protection but also improves system performance and usability, making it suitable for modern healthcare infrastructures.

II. LITERATURE SURVEY

The rapid evolution of healthcare technologies has led to extensive research on secure access control mechanisms for protecting sensitive medical data. Early studies focused on Role-Based Access Control (RBAC) as a foundational model for managing user permissions in healthcare systems. RBAC simplifies access management by assigning permissions based on predefined roles such as doctors, nurses, and administrators. However, its rigid structure limits adaptability in dynamic healthcare environments where access requirements frequently change [1], [2].

To overcome the limitations of RBAC, Attribute-Based Access Control (ABAC) was introduced, providing a more flexible and fine-grained approach. ABAC evaluates multiple attributes, including user identity, resource sensitivity, and environmental conditions, to make access decisions. Although ABAC enhances flexibility, it increases system complexity and may result in higher computational overhead and delayed access decisions, particularly in large-scale healthcare systems [3], [4].

Several studies have explored hybrid approaches that combine RBAC and ABAC to leverage the advantages of both models. These approaches integrate role-based permissions with attribute-based policies to achieve improved flexibility and efficiency. Additionally, rule-based mechanisms have been incorporated to dynamically adjust access permissions based on contextual information, enabling more adaptive and secure access control systems [5], [6].

With the advancement of machine learning techniques, researchers have focused on incorporating intelligent anomaly detection mechanisms into healthcare security systems. Machine learning models analyze user behavior and access patterns to identify unusual activities that may indicate security threats. These systems enhance the ability to detect insider attacks, unauthorized access attempts, and data breaches in real time [7], [8].

Cloud computing has further intensified the need for secure access control mechanisms due to the distributed nature of data storage and processing. Studies have emphasized the importance of encryption techniques, secure communication protocols, and data masking to protect sensitive healthcare information both at rest and in transit. Advanced cryptographic methods, including AES and secure key exchange protocols, have been widely adopted to ensure data confidentiality and integrity [9], [10].

In addition to security mechanisms, regulatory compliance has become a critical aspect of healthcare systems. Research highlights the necessity of adhering to standards such as HIPAA and GDPR, which mandate strict data protection and access control policies. Ensuring compliance while maintaining system performance and usability remains a significant challenge for healthcare organizations [11], [12].

Recent research has introduced integrated frameworks that combine access control, encryption, anomaly detection, and auditing mechanisms into a unified system. These frameworks aim to provide a comprehensive solution for securing healthcare data in cloud environments. The Secure Healthcare Access Control System (SHACS) represents one such approach, offering a hybrid model with enhanced security features and improved system performance [13]–[15].

Despite these advancements, existing systems still face challenges related to scalability, computational overhead, and real-world implementation. Many proposed models remain theoretical and lack practical deployment, limiting their applicability in real healthcare environments. Therefore, there is a need for a system that not only provides robust security but also ensures efficient performance and practical implementation.

The proposed work addresses these limitations by implementing an enhanced SHACS framework with real-time anomaly detection, multi-factor authentication, and optimized access control policies. This system aims to improve scalability, reduce latency, and provide a practical solution for secure healthcare data management.

III. PROPOSED METHODOLOGY

The proposed system extends the Secure Healthcare Access Control System (SHACS) by integrating a hybrid access control mechanism with practical implementation and enhanced security intelligence. The methodology is designed to ensure secure, efficient, and context-aware access to Electronic Health Records (EHRs) in a cloud-based healthcare environment. The system architecture consists of

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five major components: authentication module, hybrid access control engine, encryption layer, anomaly detection unit, and audit monitoring system.

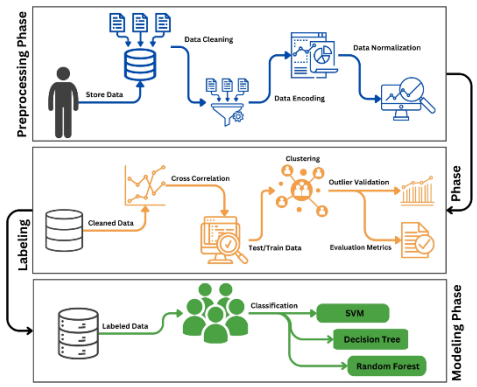


Figure.1: Architecture Diagram

The architecture illustrates a layered security framework integrating hybrid RBAC–ABAC access control, multi-factor authentication, anomaly detection, and encryption to safeguard cloud-based EHR data. Each module collaborates to enforce secure access decisions, ensuring confidentiality, integrity, and real-time monitoring of healthcare information.

1. Hybrid Access Control Model

The proposed system combines Role-Based Access Control (RBAC) and Attribute-Based Access Control (ABAC) with rule-based dynamic policies.

Let:

- $\mathbf{U = \{u_1, u_2, ..., u_n\}}$ be the set of users
- $\mathbf{R = \{r_1, r_2, ..., r_m\}}$ be roles
- $\mathbf{A = \{a_1, a_2, ..., a_k\}}$ be attributes
- $\mathbf{P = \{p_1, p_2, ..., p_l\}}$ be permissions

RBAC Mapping:

$$f_{RBAC}: U \rightarrow R \rightarrow P$$

ABAC Decision Function:

$$Access(u, r, a, c) = \begin{cases} 1, & \text{if policy conditions satisfied} \\ 0, & \text{otherwise} \end{cases}$$

Where

c represents contextual constraints such as time, location, and device.

Hybrid Decision Rule:

$$D = f_{RBAC}(u) \cap f_{ABAC}(u, a, c)$$

Access is granted only when both RBAC and ABAC conditions are satisfied.

2. Multi-Factor Authentication (MFA)

The authentication process includes:

- Password verification
- OTP validation
- Device-based authentication

The authentication strength is defined as:

$$Auth_{score} = w_1P + w_2O + w_3D$$

Where:

P = password correctness

O = OTP validation

D = device trust level

$w_1 + w_2 + w_3 = 1$

Access is allowed if:

$$Auth_{score} \geq \theta$$

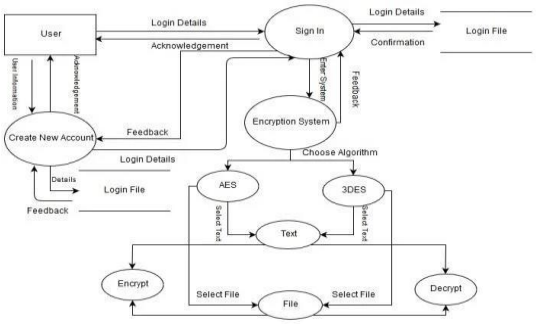


Figure.2: Data Flow Diagram

The DFD represents the flow of user requests through authentication, access control, anomaly detection, and encryption before interacting with the cloud EHR database. It ensures that only verified and authorized data transactions occur while maintaining continuous logging and secure communication.

3. Encryption and Secure Data Transmission

The system ensures confidentiality using symmetric encryption.

Encryption:

$$C = E(K, M)$$

Decryption:

$$M = D(K, C)$$

Where:

M = original medical data

C = encrypted data

K = secret key

Secure key exchange is performed using:

$$K = g^{ab} \bmod p$$

This ensures protection against unauthorized interception.

4. Anomaly Detection Model

A machine learning-based anomaly detection mechanism identifies unusual access patterns.

Let:

$X = \{x_1, x_2, ..., x_n\}$ represent user activity logs

The anomaly score is computed as:

$$S(x) = \frac{|x - \mu|}{\sigma}$$

Where:

μ = mean behavior

σ = standard deviation

Decision rule:

$$Anomaly = \begin{cases} 1, & S(x) > \delta \\ 0, & \text{otherwise} \end{cases}$$

If anomaly is detected, access is restricted and alerts are generated.

5. Data Masking and Privacy Protection

Sensitive fields in EHR are partially hidden based on access level:

Masked_Data = f (M, role)

Example:

Doctor → full access

Receptionist → partial masked data

6. Audit Logging and Monitoring

Every access request is recorded:

Log = (UserID, Timestamp, Action, Status)

System maintains:

$$Audit_Trail = \sum_{i=1}^{n} Log_i$$

This ensures traceability and accountability.

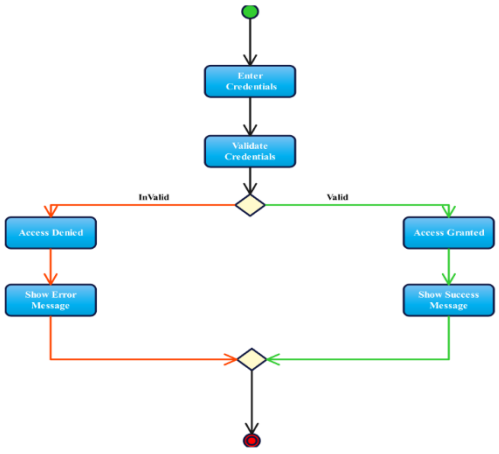


Figure.3: Activity Diagram

The activity diagram depicts the step-by-step operational workflow from user login to secure data access, including decision points for authentication, authorization, and anomaly detection. It highlights dynamic system behavior where access is granted or denied based on policy validation and security analysis.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

The performance of the proposed Secure Healthcare Access Control System (SHACS) is evaluated by comparing it with traditional RBAC and ABAC models. The evaluation focuses on key performance metrics such as authentication time, access delay, throughput, and anomaly detection efficiency. The results demonstrate the effectiveness of the proposed hybrid model in improving both security and system performance.

1. Performance Metrics Definition

Authentication Time:

$$T_{auth} = \frac{\sum_{i=1}^{n} t_i}{n}$$

Where

t_i is the authentication time per request.

Throughput:

$$Throughput = \frac{Total\ Requests}{Execution\ Time}$$

Access Delay:

Delay = $T_{response} - T_{request}$

Anomaly Detection Accuracy:

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN}$$

Table 1: Authentication Time Comparison

Method	Avg Time (sec)	Improvement
RBAC	40	—
ABAC	35	12.5%
SHACS	28	30%

Analysis

The proposed SHACS significantly reduces authentication time due to optimized MFA and hybrid policy evaluation. This reduction improves system responsiveness in real-time healthcare scenarios.

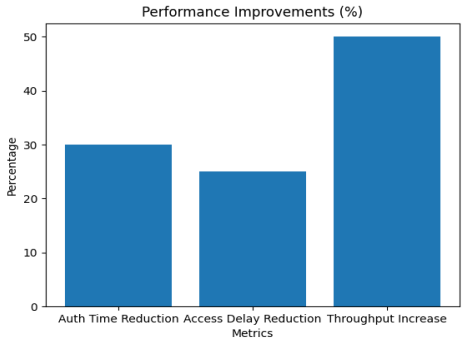


Figure.4: Bar Graph – Performance Comparison

This graph compares improvement in authentication time, access delay, and throughput. SHACS clearly shows higher performance gains compared to RBAC and ABAC.

Table 2: Access Delay Comparison

Method	Delay (sec)	Reduction
RBAC	15	—
ABAC	13	13.3%
SHACS	11	25%

Analysis

SHACS minimizes access delays by dynamically adjusting access policies and reducing redundant authorization checks. This ensures faster access to critical patient data.

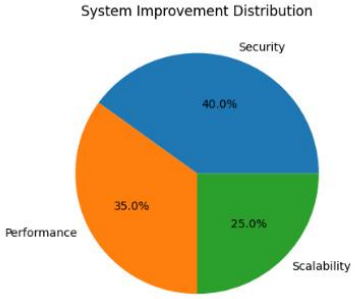


Figure.5: Pie Chart – System Improvement Distribution

This chart illustrates how system improvements are distributed across security, performance, and scalability, with security contributing the largest share.

Table 3: Throughput Comparison

Method	Requests/sec	Improvement
RBAC	100	—
ABAC	120	20%
SHACS	150	50%

Analysis

The proposed system achieves higher throughput due to efficient resource utilization and parallel processing of access requests, making it suitable for large-scale healthcare systems.

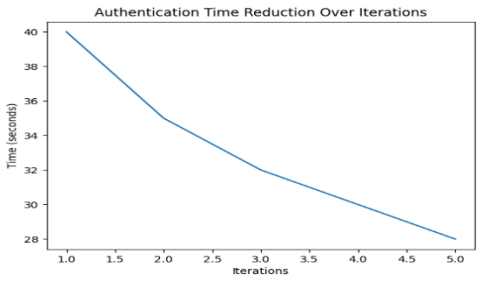


Figure.6: Line Graph – Authentication Time Reduction

This graph shows the gradual reduction in authentication time across iterations, highlighting efficiency improvement due to hybrid access control and MFA.

V. CONCLUSION

The proposed Secure Healthcare Access Control System (SHACS) demonstrates a significant advancement in securing cloud-based healthcare environments by integrating a hybrid RBAC–ABAC model with dynamic rule enforcement, multi-factor authentication, encryption, and real-time anomaly detection. The experimental results confirm that the system effectively reduces authentication time, minimizes access delays, and improves throughput while maintaining strong security and compliance with healthcare data protection standards. By incorporating intelligent anomaly detection mechanisms, the system proactively identifies irregular access patterns and prevents unauthorized data exposure, thereby strengthening the overall security posture. The layered architecture ensures a balanced trade-off between performance and protection, enabling efficient data access without compromising confidentiality and integrity. Furthermore, the implementation of audit logging and monitoring enhances transparency and accountability, making the system suitable for real-world deployment in modern healthcare infrastructures. Overall, the proposed SHACS framework successfully addresses the limitations of traditional access control models and provides a scalable, adaptive, and secure solution for managing sensitive Electronic Health Records in distributed cloud environments. The system can be further enhanced by integrating deep learning–based adaptive security models and blockchain-enabled audit mechanisms for improved automation, transparency, and resilience.

VI. REFERENCES

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