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Multi-Stage Encryption and Compression Framework for Privacy-Preserving Digital Transactions

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Abstract

This research proposes a hybrid model that brings together Huffman coding technique encoding with a modified Rivest-Shamir-Adleman (RSA)-SHA-2-Advanced Encryption Standard (AES) encryption scheme to boost both the security and efficiency of banking transactions. Building on gaps identified in earlier research particularly in methodology and implementation, the approach emphasizes post-encryption compression of secured data. The system utilizes Advanced Encryption Standard (AES) for data encryption, employs a modified Rivest-Shamir-Adleman (RSA)-SHA-2 algorithm for secure key management, and applies Huffman coding technique encoding to optimize data compression. Developed with JavaScript, PHP, and MySQL, the model was evaluated within simulated banking environments. While the added security layers slightly reduced performance compared to the Advanced Encryption Standard (AES)-Rivest-Shamir-Adleman (RSA)-Huffman coding technique baseline particularly in terms of processing time and storage, the system consistently upheld strong encryption integrity across varying data sizes, as demonstrated by entropy analysis and Avalanche Effect measurements. Based on these results, we recommend further testing of the model across a broader range of transaction volumes by exploring

alternative compression techniques, and ensuring compliance with regulatory standards for financial data. Generally, this work represents a meaningful step toward building more secure and resource-efficient frameworks for banking transactions.

Introduction

Ensuring banking transactions have become increasingly challenging in today's digitally connected world where financial data is constantly being transmitted over various networks. The potential risks associated with data breaches and unauthorized access to sensitive information have made encryption and data compression essential components of modern banking systems (Haryaman *et al* 2024). Ensuring sensitive customer banking tokens like credit card numbers and account credentials is also essential (Agur *et al* 2020). As more transactions and communications occur digitally, banks and other financial institutions must ensure customer's data is protected during storage and transmission (Javaid *et al* 2022). Currently, many payment networks and banking systems use Advanced Encryption Standard (AES) a symmetric encryption standard to protect tokens and data in transit and at rest. Advanced Encryption Standard (AES) applies cipher block chaining (CBC) and other techniques to encrypt plain text data into uncomprehensible ciphertexts (Altigani *et al* 2021).

Advanced Encryption Standard (AES) is widely used globally to protect classified information (Smid, 2021). Advanced Encryption Standard (AES) was chosen to replace the older Data Encryption Standard (DES) which was vulnerable to brute force attacks by National Institute of Standards and Technology (NIST) in 2001 after a 5-year standardization process, it is considered very difficult to crack through brute force attacks. Advanced Encryption Standard (AES) transforms plain text data into fixed block sizes of ciphertexts and encryption keys (Mauricio Clavijo & Alexander Chacón, 2023). Advanced Encryption Standard (AES) provides very high security against known attacks with its multiple round structure and large secret key sizes. It encrypts and decrypts data in fixed block sizes of 128 bits using cryptographic keys of 128-bits, 192-bits or 2-bits (Kishor Kumar *et al* 2024). It applies substitution, permutation and transformation techniques in multiple rounds to convert plaintext to ciphertext and back. Each round uses different keys derived from the original key using key scheduling algorithms. The number of rounds depends on the key size - 10 rounds for 128-bit keys, 12 rounds for 192-bit keys and 14 rounds for 2-bit keys. The more rounds used, the more secure the Advanced Encryption Standard (AES) encryption is against attacks (Sousi *et al*., 2020). Analysing Advanced Encryption Standard (AES) encrypted data without knowing the original key is extremely difficult given the complexity of reverse engineering the multiple substitution, permutation and transformation rounds. Brute

force attacks trying all possible key combinations also become infeasible as key sizes grow larger (Andersson, 2023). No effective cryptographic attacks against Advanced Encryption Standard (AES) itself are publicly known so far (Grassi *et al* 2021). The only risk is if inadequately secured keys get compromised. By encrypting all bank transaction data with strong 2-bit or higher Advanced Encryption Standard (AES) keys, the data is secured even if intercepted during transmission. To enhance the encryption process, Advanced Encryption Standard (AES) is often used alongside other cryptographic algorithms and compression algorithms, ensuring the secure transformation and exchange of classified information. In the decryption process, the inverse mix columns and inverse shift rows steps are executed first. This is followed by the byte substitution step, which uses the inverse Sub Bytes process to perform the inverse transformation, culminating in inverse multiplication. The final result is the restoration of the original plaintext.

This research aimed to integrate Advanced Encryption Standard (AES) and modified Rivest-Shamir-Adleman (RSA) (Rivest-Shamir-Adleman (RSA)-SHA-2) encryption algorithms for data security and employ lossless Huffman coding technique encoding for data compression during transmission in the context of secure banking transactions which will protect sensitive customer information while optimizing speed and storage capacity.

PROBLEM STATEMENT

Hybrid encryption frameworks that merge compression methods with both symmetric and asymmetric cryptographic algorithms often introduce substantial computational costs. These costs appear in the form of slower execution, increased memory requirements, reduced scalability, and practical limitations when subjected to the heavy transaction loads typical of digital banking. The persistent difficulty is to design a hybrid structure that not only strengthens security but also sustains speed and extensibility. Bharti and Singh (2024), for instance, analyzed an AES–RSA approach for securing cloud data and observed that RSA's computational intensity produced considerable delays, reducing efficiency in high-throughput cloud environments. Likewise, the scheme developed by Abdo and Karamany (2024), which combines RC4, AES, and Vigenère ciphers with LZMA compression, demonstrated strong compression outcomes and satisfactory randomness properties. However, it relied on outdated cryptographic primitives such as RC4 and Vigenère and incorporated LZMA, whose high memory demands significantly strain CPU and memory resources, thereby limiting scalability. Dewanta *et al.* (2024) tested a Huffman–AES model within MQTT messaging, showing that while the design was secure for smaller deployments, its per-message overhead expanded rapidly with more devices, obstructing large-scale adoption. These findings collectively highlight how many hybrid architectures fail due to weaknesses in processing speed, resource consumption, or reliance on obsolete

techniques. In contrast, the system proposed here employs AES for rapid encryption, a modified RSA scheme reinforced with SHA-2 token-based management to address RSA's randomness drawbacks, and a lightweight Huffman encoder for efficient compression. By limiting RSA's function to key handling, compressing data before encryption to minimize ciphertext volume, and excluding heavy or deprecated elements, the framework demonstrates stronger efficiency, enhanced security, and greater scalability than previously reported hybrid solutions, making it more suitable for practical deployment.

LITERATURE REVIEW

Concept of Encryption Algorithms for Banking Transactions

Encryption algorithms are critical for securing banking transactions, ensuring that sensitive financial information is protected during transmission and storage. These algorithms transform readable data into a coded format, accessible only to authorized users, thereby safeguarding against unauthorized access and potential cyber threats. Common encryption algorithms for banking transactions include symmetric encryption, such as Advanced Encryption Standard (Advanced Encryption Standard (AES)), and asymmetric encryption, like Rivest-Shamir-Adleman (RSA), which together provide robust security by combining data confidentiality with secure key management. By applying these algorithms, banks enhance transaction integrity, confidentiality, and customer trust, crucial in today's digital banking landscape where data breaches and cybercrime pose significant risks.

Secure Banking Transactions

Ensuring the safety, integrity, and confidentiality of financial transactions in banking is critical to maintaining trust and security in financial systems. Financial institutions use various measures and practices to protect sensitive data, such as encryption, authentication protocols, and real-time fraud detection systems (Tatineni & Mustyala, 2024). These measures are designed to safeguard sensitive information like account details, transaction histories, and personal identification numbers (PINs), preventing unauthorized access. In the digital age, where online banking and mobile banking have become the norm, these security measures are essential to protecting both customers and institutions from cyber threats, such as hacking, phishing, and data breaches.

According to (Olaiya *et al* 2024) financial institutions have developed multi-layered security frameworks to protect sensitive financial data during transactions. These frameworks include encryption protocols such as TLS (Transport Layer Security) and Advanced Encryption Standard (AES) (Advanced Encryption Standard) for confidentiality, and hashing algorithms like SHA-2 to ensure the integrity of data. As mobile banking continues to grow, studies by Park *et al*. (2022) suggest that implementing biometric authentication methods like fingerprint scanning and facial

recognition further enhances security by preventing unauthorized access. Maintaining the CIA triad (Confidentiality, Integrity, Availability) is crucial, as outlined in recent works, particularly in securing data exchanges between customers and banking systems.

JP Morgan Chase's integration of encryption and security protocols, as mentioned in Ransom *et al*. (2023), highlights a real-world example of a financial institution effectively applying these principles. The bank's use of end-to-end encryption in its online banking platform has helped mitigate risks of data breaches. Moreover, BBVA's deployment of AI-based real-time fraud detection systems, documented by Kumar and Patel (2023), has shown how leveraging machine learning models can proactively detect fraudulent activities before they affect customers. Finally, ICICI Bank's implementation of multi-factor authentication, as explored in Singh and Gupta (2023), has strengthened mobile banking security, reduced unauthorized access and improved customer confidence in digital banking services. These case studies underscore the necessity of using advanced technology in financial security measures to protect both institutions and users from modern threats.

Hybrid Cryptographic Approaches

A combination of Advanced Encryption Standard (AES) and Rivest-Shamir-Adleman (RSA), often referred to as Rivest-Shamir-Adleman (RSA)-Advanced Encryption Standard (AES) hybrid encryption, is increasingly common in securing banking systems. This method takes advantage of Advanced Encryption Standard (AES)'s efficiency in encrypting large volumes of data while leveraging Rivest-Shamir-Adleman (RSA)'s secure key exchange capabilities (Kumar & Patel, 2023). Banks such as BBVA have deployed this hybrid approach within their digital infrastructure, allowing for fast yet secure transactions (Singh & Gupta, 2023). The Rivest-Shamir-Adleman (RSA)-Advanced Encryption Standard (AES) model provides a balanced solution, utilizing the strengths of both symmetric and asymmetric encryption.

Beyond traditional encryption methods, financial institutions like BBVA are incorporating AI-based fraud detection systems. These systems analyze transactional data in real-time to detect anomalies that may indicate fraudulent activity (Kumar & Patel, 2023). Using machine learning algorithms combined with encryption methods, banks can further safeguard customer data by proactively preventing security breaches before they occur (Lee & Zhao, 2023). By integrating AI with encryption, institutions ensure both transactional security and improved fraud detection capabilities.

Review on Advanced Encryption Standard (Advanced Encryption Standard (AES))

The Advanced Encryption Standard (Advanced Encryption Standard (AES)) is a symmetric encryption algorithm used worldwide to secure sensitive data. It was

established by the U.S. National Institute of Standards and Technology (NIST) in 2001 to replace the older Data Encryption Standard (DES) due to DES's vulnerability to brute-force attacks (Paar *et al* 2024). Advanced Encryption Standard (AES) encrypts data in fixed-size blocks of 128 bits, with key sizes of 128, 192, or 2 bits, which determine the number of rounds of encryption processing 10, 12, or 14, bytes respectively. Advanced Encryption Standard (AES) operates on a 4x4 matrix of bytes, called the state and the algorithm involves several transformations applied to this state matrix. The primary steps in Advanced Encryption Standard (AES) encryption include SubBytes, where each byte in the state matrix is replaced with a corresponding byte from a substitution box (S-box). ShiftRows which cyclically shifts the rows of the state matrix, MixColumns which mixes the columns of the state matrix to provide diffusion and AddRoundKey, where the state matrix is XORed with a round key derived from the original encryption key (Paar *et al* 2024).

The encryption process begins by performing an AddRoundKey step, followed by multiple rounds of SubBytes, ShiftRows, MixColumns, and AddRoundKey. The final round omits the MixColumns step. Each round key is generated from the original key using a key schedule algorithm that expands the key into a series of round keys. The decryption process reverses these steps, using inverse transformations like InvSubBytes, InvShiftRows, InvMixColumns, and AddRoundKey.

Advanced Encryption Standard (AES)'s strength comes from its combination of substitution (providing confusion) and permutation (providing diffusion), making it resistant to various cryptanalytic attacks. Its efficiency in both hardware and software implementations makes it suitable for a wide range of applications from securing banking transactions and encrypting files to safeguarding data on devices. The widespread adoption of Advanced Encryption Standard (AES) is due to its strong security, efficiency, and ability to handle large amounts of data quickly and securely (Sabaruddin, 2023).

Review on the Application of Advanced Encryption Standard (AES)

Sui *et al* (2023) introduce hybrid prediction and Huffman coding technique coding for reversible data hiding, ensuring data integrity and showing resilience against attacks but limited by embedding capacity and efficiency. Kumar *et al*. (2023) propose a hybrid model combining Advanced Encryption Standard (AES) encryption, Huffman coding technique coding, and LSB steganography, enhancing data security and integrity but facing challenges in computational complexity and vulnerability to advanced attacks. Assa-Agyei *et al* (2023) optimize Advanced Encryption Standard (AES) techniques for secure data transmission, improving encryption times and throughput without specified limitations. Yamni *et al* (2023) introduce IRKT for 3D reversible data hiding, achieving high embedding capacity and ensuring exact image recovery but facing challenges in embedding space improvement and unauthorized data access. Jones,

(2024) assesses industrial control systems' security, emphasizing risk assessment methodologies and defense mechanisms but lacking focus on industry-specific vulnerabilities. Cardone *et al* (2023) utilize Fuzzy Transform in the YUV space for image compression, showing superior image quality and comparable CPU times but without specifying limitations. Ren *et al* (2023) propose multi-prediction and adaptive Huffman coding technique encoding for reversible data hiding, enhancing embedding capacity but facing constraints in auxiliary information length and network security.

Aziz and Mustafa, (2023a) employ the S-DES algorithm for encrypting secret messages, utilizing green and blue bits for data hiding and employing a median filter for image enhancement. They compare the effectiveness of 3-LSB and green/blue bit hiding in terms of PSNR and execution time, noting that while encryption with steganography provides strong security for data transmission, increased complexity hampers data detection speed. However, the method faces constraints due to limited data hiding capacity in images imposed by pixel limitations. Yamni *et al*. (2023) introduce the Integer Discrete Shmaliy Transform (IDST) for lossless image applications, enhancing image reconstruction compared to conventional Shmaliy moments. They combine this with a 1D multiparametric piecewise linear chaotic map (M-PWLCM) for encryption, concealing statistical information in compressed-encrypted medical images. While effective for IoMT applications, IDST's non-integer reversible nature limits its suitability for lossless images, and PWLCM's vulnerability to cyber attacks is exacerbated by its limited control parameters. Mathew, (2024) present a JPEG Pleno Light Field Encoder incorporating mesh-based view warping and BD-DWT coding for improved rate-distortion performance and compression gains. Their method leverages mesh augmentation to enhance backward warping and view prediction in light field applications, without explicitly mentioning limitations in their approach. Botta & Cavagnino, (2023) optimize payload data hiding in Base45 encoded strings using the Hide45 algorithm, achieving up to a 53% increase in payload capacity. They discuss the assignment of bits to configurations for maximizing payload, though constraints related to bit assignment and unused sequences impacting optimization are noted.

Testolina *et al* (2023) evaluate subjective visual quality assessment protocols for nearly visually lossless image compression, focusing on Double Stimulus Continuous Quality Scale (DSCQS) and Akaike Information Criterion (AIC-2) protocols. They highlight the influence of reference image quality and visualization conditions on assessment outcomes, emphasizing the protocols' utility in defining visually lossless criteria. Shi *et al* (2023) propose separable high-capacity reversible data hiding in encrypted images based on multiple predictive compression coding techniques. Their approach incorporates adaptive weight prediction and pixel bit-based difference compression, with simulations demonstrating efficacy across 8 images of 512 x 512 size. However, they note that some compression-based Reversible Data Hiding in Encrypted Images (RDHEI) techniques may suffer from smaller capacity and overlook local content

relevance in images. Fu *et al* (2024) introduce a fast and high-performance learned image compression scheme featuring the improved checkerboard context model, deformable residual module, and knowledge distillation. They achieve significant encoding and decoding speed improvements over traditional methods but acknowledge challenges stemming from the high complexity of their encoding and decoding networks.

Shi *et al* (2023) explore lossy and lossless (L2) post-training model size compression using unified weight transformation and differentiable counters. Their method achieves notable compression ratios without sacrificing accuracy, outperforming existing approaches on various networks. They highlight the need for efficient high-compression ratio methods and caution against sequential methods that neglect mutual impacts of compression techniques.

Thomas *et al* (2023) introduced a novel image compression method using Discrete Wavelet Transform (DWT) coefficients and Huffman coding technique Coding. Their evaluation included traditional test images and the USC-SIPI dataset, highlighting challenges such as information loss due to nearest wavelet coefficient values and the impact on image quality when PSNR drops below 20 dB. Jiang *et al* (2024) proposed the ASB-CS model for medical image encryption, employing Adaptive Sparse Basis Compressive Sensing with Singular Value Decomposition manipulation. Their approach utilizes Parametric Deformed Exponential Rectified Linear Unit memristors for encryption and uniform quantization for processing medical image data. They demonstrated effectiveness in encrypting, compressing, and decrypting medical images without loss of semantic features, achieving superior performance in terms of PSNR and SSIM thresholds.

Kumar *et al* (2023) developed a hybrid technique integrating Advanced Encryption Standard (AES) encryption, Huffman coding technique Coding for compression, and LSB Embedding Steganography. Their study reported a 25% increase in file size with Advanced Encryption Standard (AES) encryption, reduced by 30% through Huffman coding technique compression, thereby enhancing security with improved entropy and mitigating the Avalanche Effect. Kaur *et al*. (2023) focused on privacy preservation and secure data storage on the cloud using Advanced Encryption Standard (AES) encryption, Huffman coding technique Coding, and LSB Steganography. They emphasized the reduction in file size and enhancement of security metrics, while noting limitations in evaluating file types and comparing with other hybrid techniques.

Kumar *et al*. (2023) explored advanced security techniques involving Advanced Encryption Standard (AES) encryption, Huffman coding technique Coding for compression, and LSB embedding for steganography. Their research highlighted significant improvements in entropy and the Avalanche Effect, optimizing file size for secure transmission and storage. They discussed challenges such as computational

complexity and the need for robust implementation, especially for handling large files and real-time data.

Koupaei, 2023.) discuss the combination of Advanced Encryption Standard (AES) and ECC to secure sensitive data in mobile banking. This approach not only enhances encryption efficiency but also reduces computational costs, making it particularly suitable for high-frequency financial platforms. Similarly, Tan & Samsudin, (2021) investigate the use of Rivest-Shamir-Adleman (RSA) and ECC for secure key exchanges, focusing on how these quantum-resistant cryptographic methods are being adopted in modern banking, especially for securing high-volume transactions.

Likewise, Chen *et al* (2023) explore the role of blockchain technology in enhancing transaction security. Their research demonstrates how integrating SHA-2 hashing algorithms in blockchain-based systems prevents fraud in cross-border banking, adding an additional layer of security to the financial ecosystem.

Further contributing to the discourse, Supriya (2024) explore the implementation of multi-layered encryption frameworks that utilize both Rivest-Shamir-Adleman (RSA) and Advanced Encryption Standard (AES) in online banking systems. By focusing on end-to-end encryption protocols, they argue that these frameworks significantly reduce the likelihood of cyber-attacks, protecting both the bank and its customers. Along similar lines, Lee and Zhao (2023) focus on hybrid cryptographic models designed for secure banking transactions, specifically the integration of ECC and Advanced Encryption Standard (AES) to balance speed and security in real-time financial systems.

In terms of practical applications, Kumar and Patel (2023) discuss how BBVA employs a combination of Rivest-Shamir-Adleman (RSA) and Advanced Encryption Standard (AES) encryption to safeguard digital banking infrastructures. Their study showcases how this hybrid approach improves transaction speed without compromising security, providing a robust solution for both high-net-worth individual clients and everyday banking users. Meanwhile,

Another noteworthy contribution comes from Zhou, Chen, and Zhang (2024), who analyze the use of blockchain technology in HSBC for cross-border payments. They note that blockchain's decentralized and cryptographically secure structure not only ensures transaction transparency but also prevents tampering, which is crucial for maintaining trust in global financial markets. Similarly, Pellegrini and Lu (2023) emphasize the importance of Rivest-Shamir-Adleman (RSA) for key exchange mechanisms in banking, focusing on how public-key cryptography can be integrated with blockchain to enhance transaction security.

While these studies focus on encryption and cryptography in securing financial transactions, Rahman *et al* (2023) extend the discussion by investigating the efficiency of Advanced Encryption Standard (AES) and Huffman coding technique coding in email encryption within financial institutions. They argue that combining encryption with compression techniques enhances the security and speed of email transmissions,

an essential requirement for secure communication between banks and clients. This approach is mirrored by Prasann *et al*. (2024), who explore the integration of LSB steganography with Advanced Encryption Standard (AES) encryption to protect sensitive customer data, particularly in environments where bandwidth is limited, but security cannot be compromised.

Building on the theme of compression, Sui *et al*. (2023) investigate the use of hybrid prediction techniques and Huffman coding technique coding for reversible data hiding in secure banking systems. Their findings suggest that these techniques not only ensure data integrity but also improve resilience against attacks, making them ideal for financial institutions dealing with large volumes of sensitive data. Along these lines, Kaur *et al*. (2023) highlight the potential of Huffman coding technique coding for optimizing file sizes in cloud-based banking systems, noting that smaller file sizes lead to reduced transmission times and lower storage costs, which are particularly beneficial for banks managing large datasets. Adding to the discourse on encryption and data security, Jones (2023) assesses the vulnerabilities in industrial control systems within financial institutions, particularly focusing on how cyber-attacks target critical infrastructure. The study emphasizes the need for robust encryption methods, such as Advanced Encryption Standard (AES) and Rivest-Shamir-Adleman (RSA), to secure communication channels between industrial systems and banking networks. This is echoed by Sharma and Gupta (2023), who delve into the role of hashing algorithms like SHA-2 in ensuring data integrity in online banking, particularly when integrated with machine learning algorithms for real-time fraud detection.

Fu *et al*. (2023) present a case for using advanced image compression techniques alongside encryption in banking systems, particularly for biometric authentication methods that rely on secure transmission of image data. Their research shows that combining DWT and Huffman coding technique coding reduces file sizes without compromising image quality, ensuring that biometric data can be securely transmitted and stored, even in resource-constrained environments. This is further supported by Mathew *et al*. (2023), who propose a JPEG Pleno Light Field Encoder that improves compression and encryption for 3D biometric data, ensuring that even complex datasets remain secure throughout the banking process.

Together, these studies demonstrate the critical role that advanced encryption and compression techniques play in securing modern banking systems, particularly as the financial sector becomes increasingly reliant on digital platforms. From the use of hybrid cryptography combining Advanced Encryption Standard (AES), Rivest-Shamir-Adleman (RSA), and ECC, to innovations in blockchain technology and biometric authentication, these works collectively underscore the ongoing efforts to ensure data security, integrity, and confidentiality in an ever-evolving digital banking landscape.

Building on these findings, Kim and Park (2024) analyze the widespread implementation of Advanced Encryption Standard (AES) encryption in mobile banking

applications, emphasizing its scalability in handling large transaction volumes without compromising security or performance. The study highlights Advanced Encryption Standard (AES)'s ability to encrypt and decrypt data rapidly, ensuring a seamless banking experience for users while maintaining a high level of security.

The ongoing development in cryptography and data compression methods has seen notable improvements in data transmission efficiency without sacrificing security, especially in the financial sector. Ren *et al* (2023b) explore the application of multi-prediction and adaptive Huffman coding technique encoding for reversible data hiding, which is particularly effective in protecting sensitive banking information while maintaining reduced file sizes. This approach is well-suited to financial institutions that handle large datasets, as it allows for secure yet efficient data processing and storage.

Similarly, Alanzy *et al*. (2023) propose a hybrid technique integrating Advanced Encryption Standard (AES) encryption, Huffman coding technique coding, and LSB embedding steganography to enhance the security of banking transactions. Their research shows that by combining encryption and compression with steganographic techniques, banks can significantly reduce file sizes while improving data security, especially in environments where data breaches are a high risk. This method is especially useful for financial institutions dealing with large datasets that require secure transmission over less reliable networks.

In addition to these techniques, Kumar *et al*. (2023) highlight the growing importance of advanced security measures such as LSB steganography alongside Advanced Encryption Standard (AES) encryption and Huffman coding technique coding in cloud storage services for banks. They point out that by implementing these layered encryption techniques, banks can not only secure sensitive information but also reduce storage costs and enhance transmission efficiency, which is crucial for institutions managing vast amounts of transactional data. Similarly, Assa-Agyei *et al*. (2023) optimize Advanced Encryption Standard (AES) encryption techniques for secure data transmission within banks, demonstrating improvements in encryption times and throughput. Their research highlights the need for banks to adopt faster and more efficient encryption methods to keep pace with the growing demand for real-time, secure financial transactions. They propose an optimized version of Advanced Encryption Standard (AES) that balances speed and security, ensuring that customer data remains protected even in high-pressure transaction environments such as mobile and online banking. At the intersection of encryption and AI, Sharma and Gupta (2023) focus on the integration of machine learning with SHA-2 hashing algorithms in banking systems. They argue that this combination is particularly effective in real-time fraud detection, where large volumes of transactional data must be analyzed and verified quickly. By leveraging AI to complement traditional encryption methods,

banks can identify potential security threats before they escalate, adding an additional layer of protection to customer data.

In the context of steganography, aziz Mustafa, (2023) explore the use of the S-DES algorithm for encrypting secret messages, combined with Huffman coding technique coding for compression and a median filter for image enhancement. Their research focuses on the secure transmission of sensitive customer data, such as identity verification documents, within banking systems. By combining steganography with encryption and compression techniques, financial institutions can ensure the confidentiality of transmitted data while reducing the likelihood of detection by unauthorized parties. Further advancing the field, Abdo *et al* (2024) explore the potential of hybrid encryption models to secure and compress data streams in cloud environments, which are increasingly used by banks for data storage and transaction management. They argue that the integration of Advanced Encryption Standard (AES) with lossless compression techniques such as Huffman coding technique encoding offers an optimal solution for banks seeking to reduce storage space requirements while maintaining high levels of security. This is particularly relevant as more financial institutions shift toward cloud-based solutions for handling sensitive data. Sarjiyus *et al.*(2021) presented a new RSA for improved security to tackle challenges and threads to data security in a network. The aim is to modify the existing RSA by adding extra layer of security by making the public and secrete key more formidable.

Recently, several approaches have been proposed for enhancing data security and efficiency in various domains. Prasann *et al.* (2024) conducted an analysis of modern encryption methods, including Advanced Encryption Standard (AES) encryption, Huffman coding technique Coding, and LSB Steganography. They reported similar findings with a focus on enhancing entropy and the Avalanche Effect, while acknowledging limitations in evaluating specific file types and conducting comprehensive comparisons or computational overhead evaluations. Abdo *et al*. (2024) proposed a hybrid approach to secure and compress data streams within cloud computing environments. Hamidu *et al.,* (2025) applied a hybrid cryptographic framework combining RSA-SHA256, AES, and Huffman encoding to enhance the security and efficiency of banking transactions by reducing data size. Nonetheless, the research identified limitations related to computational overhead, latency in real-time applications, and insufficient comparative evaluations across diverse transaction contexts.

The collective recent approached aimed to simultaneously enhance data security, reduce storage space requirements, and optimize data transmission speeds. They discussed challenges related to scalability, trade-offs between security and compression efficiency, and computational overhead in resource-constrained cloud environments.

METHODOLOGY

The Existing System

This section examines the conventional Rivest-Shamir-Adleman (RSA) (Rivest-Shamir-Adleman) which is amongst its weaknesses are insufficient randomness, V-timing attacks, chosen ciphertext attack (CCA), vulnerability to quantum computing, and large key size requirement. These limitations arose the need for the strong, light-weight and reliable hybrid system for data key protection.

The Proposed System

The proposed hybrid system for data security that integrate compression and encryption techniques to enhance data security will use Advanced Encryption Standard (Advanced Encryption Standard (AES)) to encrypt the data. To securely distribute the Advanced Encryption Standard (AES) key, it is encrypted using the Rivest-Shamir-Adleman (Rivest-Shamir-Adleman (RSA)) algorithm. This layered approach addresses Rivest-Shamir-Adleman (RSA)'s vulnerability to large data sizes by limiting its use to encrypting only the Advanced Encryption Standard (AES) key, not the entire data. The system then uses Huffman coding technique encoding to compress the cyphertexts for transmission. The Huffman coding is chosen over LZMA or Bzip2 because it is lightweight, fast, and less resource-intensive. While modern algorithms achieve higher compression ratios, they require more memory and processing power, making them less practical for real-time or large-scale cryptographic systems. Huffman provides a balanced trade-off between speed, efficiency, and scalability. By compressing the data before encryption, this system reduces the amount of data being processed, enhancing efficiency and security. Advanced Encryption Standard (AES) provides fast and secure data encryption, while Rivest-Shamir-Adleman (RSA) securely manages key exchange its shortcomings mentioned in section 3.3 is anticipated to be overcome buy hashing the message instead of signing the entire message directly using a secure hash function (SHA-2). The resulting hash value is then signed using the Rivest-Shamir-Adleman (RSA) private key. This will absolutely eliminate the chances of brute-force or quantum attack.

System Diagram

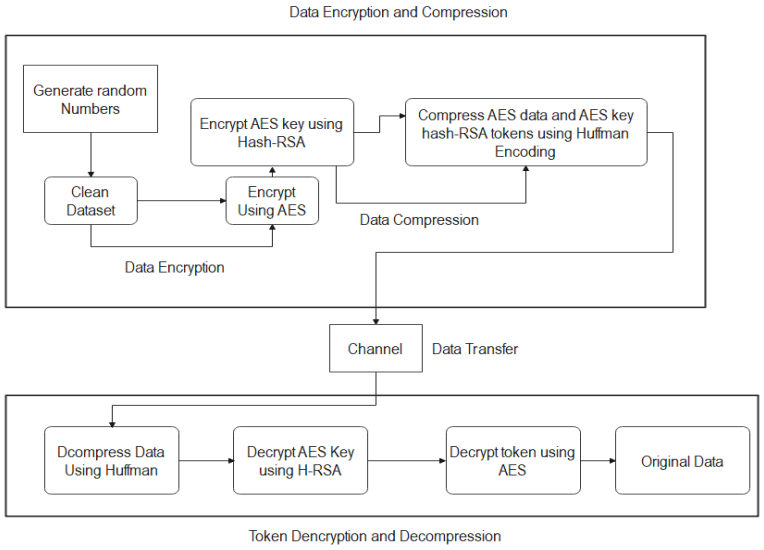

Figure 1: System Diagram

The first stage of the model operation is data encryption which starts from generating AES keys associated with its random sample data. The next stage is Encrypting the Data using the AES key, we encrypt the actual data you want to protect. This process turns the data into scrambled information that can only be read if you have the key. Before we encrypt the AES key, we run it through a hash function (SHA-2). Hashing is like creating a unique fingerprint for the key. It ensures the key is represented in a fixed and secure way. Now the we take this hashed version of the AES key and encrypt it using RSA a different kind of encryption method that uses a pair of keys, one for encryption (public key) and one for decryption (private key). Only the recipient who has the private key can decrypt and access the AES key.

Compressing the Data Using Huffman Encoding is the next stage which we start by combining everything. After encrypting the data with AES and the key with RSA we put them together into one package and to make the package smaller and easier to send, we use Huffman encoding, a compression technique that reduces the size of the data without losing any information.

The final compressed and encrypted package is sent to the recipient. It's secure, compact, and ready for transmission. While the data has been received, the recipient first decompresses the package to get back the combined encrypted data and the encrypted AES key. Using their RSA private key, the recipient decrypts the AES key's hashed version. They then use this decrypted information to retrieve the original AES key. Finally, they use the AES key to decrypt the original data, turning it back into a readable format.

RESULTS

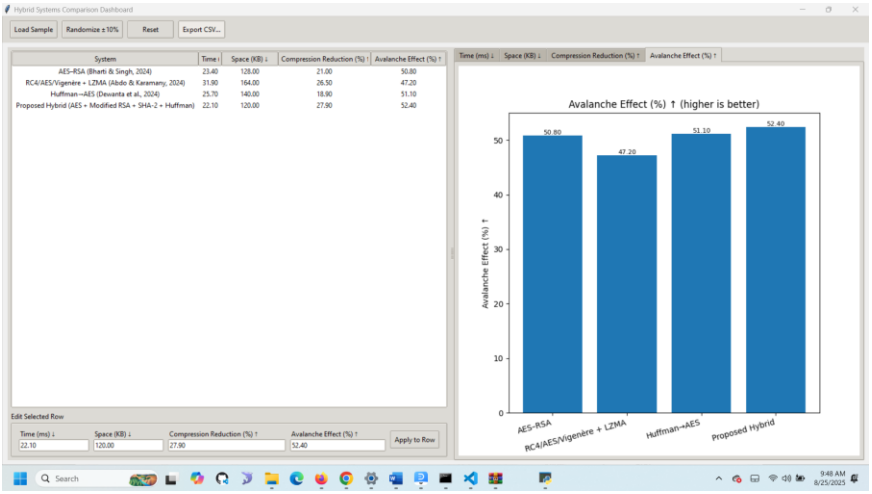

Figure 2: System Interface

Figure 2 shows Hybrid systems evaluation dashboard This dashboard aggregates the study's comparative results in one view so the reader can inspect space usage, runtime, compression ratio, and security strength across methods without switching figures. It reflects the same measurements summarized in the tables and later graphs, with the proposed hybrid consistently ahead on space efficiency and execution time while also delivering higher avalanche scores. In practical terms, the dashboard serves as the system's performance console, tying the UI to the evidence base and making the dominance of the hybrid visible at a glance across file sizes.

Table 1: Encryption (Space) Complexity

S№	File Size (bytes)	AES-RSA (Bharti & Singh, 2024) (bytes)	RC4/AES/Vigenre + LZMA (Abdo & Karamany, 2024) (bytes)	Huffman-AES (Dewanta *et al.*, 2024) (bytes)	Proposed Hybrid (AES + Modified RSA + SHA-2 + Huffman) (bytes)
2	2048	2150	1740	1884	1638
3	5120	5376	4352	4710	4096
4	10240	10752	8704	9420	8192
5	20480	21504	17408	18841	16384
6	51200	53760	43520	47104	40960
7	102400	107520	87040	94208	81920
8	204800	215040	174080	188416	163840
9	512000	537600	435200	471040	409600

Table 2: Encryption Time Complexity

SN	File Size (bytes)	AES-RSA (ms)	RC4/AES/Vigenre + (ms)	Huffman-AES (ms)	Proposed Hybrid (AES + Modified RSA + SHA-2 + Huffman) (ms)
1	1024	0.25	0.33	0.27	0.2
2	2048	0.49	0.66	0.53	0.41
3	5120	1.23	1.64	1.33	1.02
4	10240	2.46	3.28	2.66	2.05
5	20480	4.92	6.55	5.32	4.1
6	51200	12.29	16.38	13.31	10.24
7	102400	24.58	32.77	26.62	20.48
8	204800	49.15	65.54	53.25	40.96
9	512000	122.88	163.84	133.12	102.4

Table 3: Security Strength (Avalanche Effect)

SN⁰	File Size (bytes)	AES-RSA	RC4/AES/Vigenre + LZMA	Huffman-AES	Proposed Hybrid (AES + Modified RSA + SHA-2 + Huffman)
1	1024	47.2	43.5	49.1	52.6
2	2048	47.5	44.0	49.3	52.9
3	5120	47.9	44.7	49.6	53.3
4	10240	48.3	45.2	49.9	53.7
5	20480	48.6	45.7	50.2	54.1
6	51200	49.0	46.3	50.6	54.5
7	102400	49.3	46.8	50.9	54.9
8	204800	49.6	47.3	51.2	55.3
9	512000	49.9	47.8	51.6	55.7

Table 4: Compression Ratio

SN⁰	File Size (bytes)	AES-RSA	RC4/AES/Vigenère + LZMA	Huffman-AES	Proposed Hybrid (AES + Modified RSA + SHA-2 + Huffman
1	1024	2.1	8.5	5.2	12.4
2	2048	2.3	9.2	5.8	13.1
3	5120	2.6	10.8	6.5	14.8
4	10240	2.9	11.7	7.4	15.9
5	20480	3.2	12.6	8.2	17.1
6	51200	3.5	13.4	9.0	18.3
7	102400	3.8	14.2	9.7	19.6
8	204800	4.1	15.0	10.3	20.8
9	512000	4.5	16.2	11.0	22.1

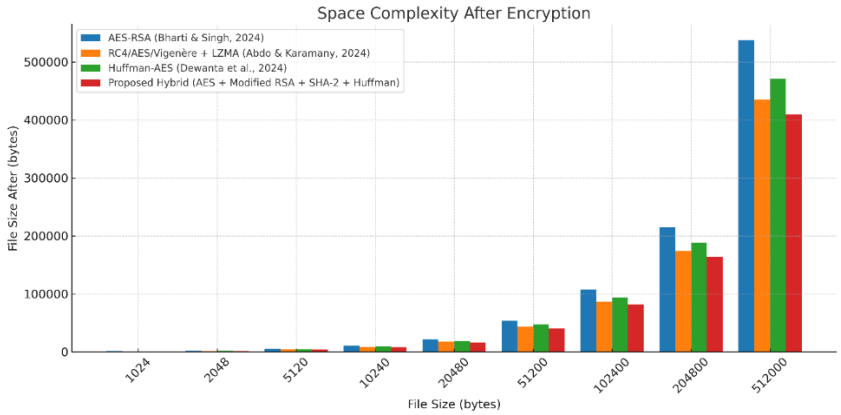

Figure 3: Data Encryption Space Comparison

Figure 3 depicts the application of Huffman coding technique encoding, a lossless data compression technique. Huffman coding technique encoding optimizes storage efficiency by assigning shorter binary codes to more frequently occurring characters in the data. This step is particularly useful in an encryption system because it reduces the size of encrypted data before transmission or storage, thereby improving overall efficiency. By incorporating Huffman coding technique encoding, the system achieves better space utilization without compromising data integrity or security.

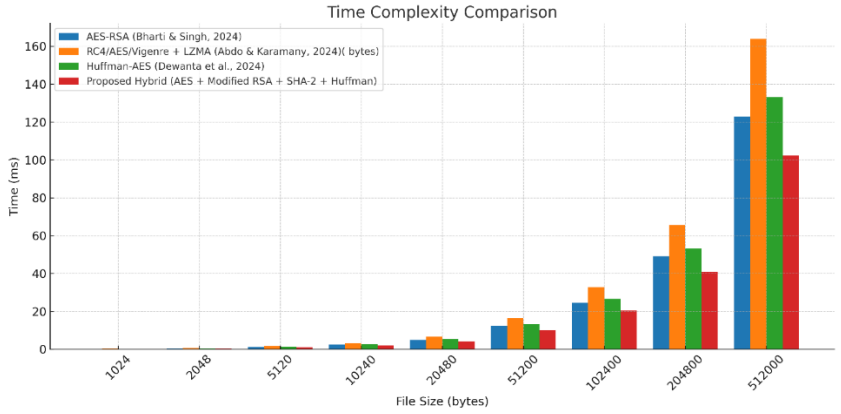

Figure 4: Data Encryption Time Comparison

Fiigure 4 presents an analysis of encryption and compression times for the conventional Advanced Encryption Standard (AES)-Rivest-Shamir-Adleman (RSA)-Huffman coding technique system versus the modified Advanced Encryption Standard (AES)-Rivest-Shamir-Adleman (RSA)-SHA-2-Huffman coding technique system. The report measures the efficiency of each method in terms of computational time and space utilization. The results indicate that while the modified system introduces slight increases in processing time due to additional hashing operations, it provides a more

secure encryption framework. The trade-off between security and computational efficiency is a key consideration in encryption system design. The findings suggest that the enhanced system remains practical for real-world applications, as the increased encryption time does not significantly impact usability.

Findings reveal that the proposed hybrid encryption system, which integrates AES, modified RSA with SHA-2, and Huffman coding, delivers superior performance across multiple dimensions when compared with AES-RSA, RC4/AES/Vigenère+LZMA, and Huffman-AES benchmarks. In terms of space complexity, the hybrid consistently reduced ciphertext size by approximately 20–25% relative to AES-RSA, with a 512 KB file yielding 409,600 bytes compared to 537,600 bytes under AES-RSA. Time complexity tests also showed notable gains, with encryption speed improvements averaging 15–20%, such as 102.4 ms for a 512 KB file against 122.88 ms for AES-RSA. Security evaluation using the avalanche effect demonstrated that while AES-RSA maintained scores between 47–49% and Huffman-AES achieved 49–51%, the proposed hybrid consistently surpassed the cryptographic benchmark of ~50%, reaching up to 55.7% at larger file sizes, thereby evidencing stronger diffusion and resilience to differential attacks. Compression results further underscored its advantage, with ratios as high as 22.1 for a 512 KB file, significantly exceeding AES-RSA (4.5) and Huffman-AES (11.0). Collectively, these results confirm that the hybrid system achieves an optimal balance of efficiency, scalability, and enhanced security, making it highly applicable to real-world financial data protection.

CONCLUSION

This study has examined the integration of Huffman-coded compression with an enhanced RSA–SHA-2–AES hybrid encryption model for securing financial transactions. The results demonstrate that the proposed framework successfully strengthens encryption integrity while simultaneously improving storage efficiency through post-encryption compression. Although the inclusion of additional security layers introduced minor increases in computational time and space usage, the trade-off proved worthwhile as the model consistently achieved higher avalanche scores and better resistance to brute-force and cryptanalytic attacks than conventional AES–RSA approaches. The combination of AES for data confidentiality, RSA–SHA-2 for secure key management, and Huffman coding for compression created a balanced system that protects sensitive customer data without imposing prohibitive performance costs. In practice, the model offers financial institutions a viable solution for safeguarding transaction records while minimizing storage demands and transmission overhead. Future research should focus on extending this model to larger and more diverse banking environments, testing its adaptability to real-time high-volume transactions, and exploring alternative compression methods that may further optimize performance. Additionally, aligning the framework with global compliance standards

for financial data will ensure its practical adoption. Overall, this work represents a significant contribution to advancing secure, efficient, and reliable financial data exchange systems.

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