HYBRID ENCRYPTION MODEL FOR SECURE TOKEN DISTRIBUTION SCHEME

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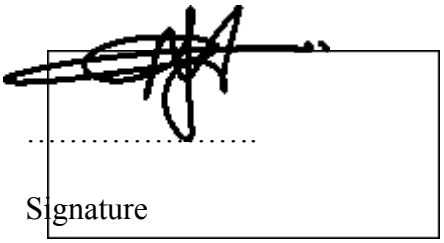
Declaration by the candidate

This proposal/thesis is my original work and has not been presented for award of a degree in any other University or for any other award.



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DEDICATION

This work is dedicated to Mr. and Mrs. Kamweru for their unwavering mentorship and support, to Professor Esther Gicheru for her inspiring patronage and encouragement.

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ABBREVIATION AND ACRONYMS

APT.....Advanced persistent threat

RSA.....Rivest-Shamir-Adleman

ECC.....Elliptic curve cryptography

AES.....Advanced Encryption Standard

DES.....Data Encryption Standard

FHE.....Fully Homomorphic Encryption

HTTPS.....Hypertext transfer protocol secure

ECDH.....Elliptic Curve Diffie-Hellman

SSE.....symmetric searchable encryption

ABE.....Attribute-based encryption

API.....Application programming interface

MitM.....Man in the middle attack

IDSs.....Intrusion detection systems

SSL.....Secure Sockets Layer

TLS.....Transport Layer Security

APIs.....Application Programming Interfaces

OPERATIONAL DEFINITION OF TERMS

Encryption- Encryption is the process of converting information into a secret code that hides the information's true meaning

Hybrid encryption- Combination of more than one encryption algorithm in securing data.

Hashing-Converting a message into a hash, which is a unique identifier. Hashing which is one way encryption, is used to ensure the authenticity of data and that it has not been tampered with.

Vulnerability- A weakness or flaw in an application, either from design errors or implementation bugs, that can be exploited by an attacker to cause harm to the application's stakeholders.

Firewall - A network security system that controls incoming and outgoing traffic, determining whether to permit or block specific connections based on predefined security rules.

Malware -Software installed on a computer without the user's consent, designed to perform harmful actions such as stealing data, passwords, or financial information.

Advanced persistent threat (APT)- A long-term, sophisticated cyberattack in which an intruder secretly gains and maintains access to a network, enabling the continuous theft of sensitive data over an extended period.

An attack - Is the deliberate execution of one or more steps with the intent of causing a security violation, such as unauthorized control of a client device.

An adversary - Is the source or threat agent behind a potential attack, and once a threat is activated, it is frequently referred to as an attacker.

ABSTRACT

In the current era of digital communications, the safety of token transmission is crucial especially, in securing sensitive data and in distributed systems. The classical encryption algorithms, despite their popularity, are not always effective in ensuring stringent security levels during the transmission of tokens. Communication systems are prone to many types of attacks, including brute force, replaying tokens, man-in-the-middle (MITM), and token modification, among others. In this paper, a hybrid encryption model is presented to ensure the safety of token distribution by combining three encryption algorithms: Secure Hash Algorithm (SHA-2), ChaCha20, and Rivest-Shamir-Adleman (RSA). The model is designed to overcome the weaknesses of the single encryption methods through a combination of the strengths of their methods to ensure data integrity as well as confidentiality during the transmission process. SHA-2 is used to ensure the integrity of data and prevent brute force attacks, and ChaCha20 is used for symmetric encryption of tokens. The study discusses the use of hybrid cryptography in the areas of healthcare, education, and commerce with a particular focus on the protection of data and safeguarding sensitive information, such as user authorization and authentication data. RSA is an asymmetric encryption technique employed in secure key exchange, thereby making the scheme resistant to key compromise. The hybrid encryption protocol was implemented in a controlled environment with the help of a Monte Carlo simulation, which would employ Python cryptographic libraries. Randomized attacks were implemented to test the system's resilience to see its resistance to brute force attacks, replay attacks, MITM attacks, and token modification attacks. Efficiency ratios like speed of encryption, key generation, and computational overhead were also evaluated. The findings indicate that the suggested hybrid encryption model can enhance security by 44.44% more than current encryption models, without negatively affecting system efficiency, which is a solid solution to secure the distribution of tokens in vulnerable transmission systems.

CHAPTER ONE

INTRODUCTION

1.0 Introduction

This Chapter provides a background of the fundamental concepts, including the problem informing the study and the justification for the necessity to provide Hybrid encryption that can be used in various distributed systems, including the security of token transmission. It further outlines the research objectives, lists the research questions, defines the scope, assumptions, and significance of the study.

1.1 Background of study.

Tokens are a type of digital asset that utilize encryption techniques to secure transactions and verify the authenticity of the data.Cryptographic tokens, including Non-Fungible Tokens (NFTs), are used to demonstrate ownership of digital assets on blockchains, authentication of users into systems or access to service (Truong et al., 2023). The security and efficiency of token encryption systems have become key considerations as the reliance on digital technology and the increase in proliferation of distributed systems. Cryptographic tokens can serve various purposes, including as a means of exchange, a representation of ownership or voting rights, or as a form of digital identity. Tokens are instrumental in ensuring the integrity and confidentiality of sensitive data, especially in scenarios where access control is paramount. The main objective of a cyber defense system is that data should be confidential, available and without loss of its integrity (Shaukat et al., 2020).

Data security provides individual users' data privacy, confidentiality, data integrity, and data provenance authentication. Digital signatures, hash functions, message authentication codes, and encryption are four key cryptographic techniques used to achieve these goals. In cryptography, a ciphertext is the content of encrypted message that is in an unreadable format to outsiders, where the technical process of transforming the ciphertext into a readable format is called decryption.(Kuppuswamy et al., 2023)

Token encryption commonly relies on two main types of cryptographic algorithms: symmetric key cryptography, which uses a single key for both encryption and decryption, and asymmetric key cryptography, which utilizes a key pair—the public key for encryption and

the private key for decryption. A fundamental aspect of cryptography is key distribution, which ensures that encrypted data can be securely exchanged between communicating entities. In classical cryptography, safe key distribution is crucial for maintaining the confidentiality and integrity of transmitted information (U. E. Orji, 2020).

Hybrid cryptographic algorithms have gained prominence in various domains due to their ability to enhance security and operational speed. (U. E. Orji, 2020) discussed the enhanced security provided by hybrid encryption techniques in communication and financial transactions, utilizing both symmetric and asymmetric encryption methods. These various combinations have been used to provide security on tokens.For instance, hybrid encryption can be achieved by combining algorithms such as Advanced Encryption Standard (AES), Elliptic Curve Cryptography (ECC), and Rivest–Shamir–Adleman (RSA), while Secure Hash Algorithm (SHA-256) is utilized to guarantee data integrity and authentication. (Noor et al., 2022). These models seek to address the shortcomings of individual encryption methods by combining multiple algorithms to improve both security and efficiency across different applications.

As technology advances, cryptographic tokens are anticipated to become increasingly significant in the digital economy, facilitating innovative financial transactions and transforming the management and exchange of assets.

1.2 Problem Statement

Security breaches to sensitive information affects almost every sector, especially those with ‘valuable’ data such as the health sector, financial sector, government entities with public data among others. Tokens are digital or physical assets that represent a unit of value or are secured to a service or system. These tokens are often used in authentication processes to streamline the login process such as two-factor authentication, where a user must provide something they know (like a password) and something they have (like a cryptographic token) to access a system.

One common type of attack on token cryptosystems is brute force attacks (Kumar & Badal, 2019), where adversaries utilize trial-and-error tactics to decode private information.Others include, Man in the middle attack,lack of proper Token randomization, lack of proper key revocation mechanisms, lack of enough Hybrid measures to protect specific data types like tokens and outrageous computing overheads on token cryptosystems.When this is not addressed, it can cause vulnerabilities like token replay attacks, Phishing,Token

exposure,Token modification and even to some extreme dangerous cases like key exposure which can lead to vulnerabilities in the encryption process, potentially compromising the confidentiality of the encrypted data and further, contribute to unauthorized entry into systems or access to services (Liu et al., 2023). Advance persistence threat attacks are becoming a concern with such valnerabilities. With APTs, their ability to go undetected for prolonged periods, poses a severe threat to organizations and individuals (Alsanad & Altuwaijri, 2022), (Dar et al., 2021). Compromised tokens can be used for fraudulent activities, consumers who unknowingly use illegal tokens can become unwitting accomplices in fraudulent activities which may lead to legal and financial repercussions like fines or even imprisonment. Several instances of unauthorized (or improperly registered) token distribution have already occurred in the cryptocurrency industry, resulting in fines from regulators, lawsuits, and obligations to return all funds raised to token purchasers (Jin et al., 2021). By modifying tokens, attackers can potentially bypass security measures and introduce malicious content into the system, leading to misinformation or unauthorized access to protected data. This may be a clear contribution due to the lack of enough hybrid cryptosystems to specifically protect specific data types like tokens (Reddy et al., 2023).

Traditional methods of cyber defense like like access control, firewalls, malware scanners, and intrusion detection and prevention technologies have not adequately protected these systems and networks and could be circumvented by sophisticated attackers. Except for a few security reports, our community lacks knowledge of these vulnerabilities, including its scope and effects.(Jin et al., 2021) As a result, the target of this research was to fill the void by examining weaknesses found in encryption protocols used for transmission, and gaps from relevant literature that contribute to security threats.

The main issue that this study is dealing with is the fact that the use of one encryption algorithm is quite insufficient to ensure the safety of tokens during the transmission in the conditions of more and more sophisticated cyber-attacks. The existing solutions lack a holistic solution that will support healthy security alongside effective performance. To address these issues, this study suggests a hybrid encryption model which can be used to improve the security of tokens by combining several cryptographic algorithms; that is, SHA-2, ChaCha20, and RSA in a chain. The hybrid model is set to offer the advantages of symmetric and asymmetric encryption that would secure key exchange, rapid encryption, and effective defenses against the typical attacks like brute force, token relay, and MITM.

This research aims at creating, deploying, and testing a hybrid cryptographic protocol that will secure the distribution of tokens by solving the vulnerability of the single encryption mechanisms. This study has a solution that will guarantee both integrity and confidentiality of the tokens sent across the network, as well as authenticity of the tokens, and at the same time, the solution is performance efficient as it combines the capabilities of SHA-2, which provides integrity, ChaCha20, which provides fast symmetric encryption, and RSA which provides secure exchange of keys. This study measures the effectiveness of the hybrid encryption model to address the risk of attacks and its capacity to work efficiently in real-world conditions through a controlled simulation environment.

1.3 Objectives of the Study

1.3.1 Main objective

To develop a secure cryptographic encryption protocol for secure token distribution.

1.3.2 Specific objectives

i. To investigate the techniques that have been used in the transmission of tokens.

ii. To design an efficient cryptographic protocol for the transmission of tokens.

iii. To implement the cryptographic protocol for the transmission of tokens

iv. To analyze the efficiency of the hybrid encryption protocol.

1.4 Research Questions

i. What are the weaknesses of the techniques currently being used in the transmission of tokens?

ii. How can an efficient cryptographic protocol for the transmission of tokens be designed?

iii. How can the cryptographic protocol for the transmission of tokens be implemented?

iv. How efficient is the cryptographic protocol for the transmission of tokens?

1.5 Significance of the study

The significance of this study lies in the importance of protecting sensitive information in the digital age. With the increasing reliance on digital transactions and communication, the need to safeguard tokens from unauthorized access is crucial. By conducting this study, researchers can contribute to the development of more effective and reliable methods for

protecting sensitive data where the use of hybrid encryption can overcome limitations associated with single encryption algorithms, ensuring a more secure communication channel (Lu et al., 2023). This can have far-reaching implications for various industries, including finance, healthcare, and e-commerce, where secure token transmission is essential for maintaining trust and confidentiality.

1.6 Justification of the study

Security of tokens is a crucial factor in maintaining the integrity and confidentiality of sensitive information. (Zhang, 2021) emphasized the importance of authentication to prevent the misuse of tokens obtained illegally, contributing to strengthening token integrity and reducing the risk of unauthorized access. It is crucial to consider the encryption mechanisms employed to safeguard these tokens, Hybrid encryption, has been recognized for enhancing the security of communication and financial transactions. By utilizing a combination of encryption schemes, hybrid encryption provides a higher level of security compared to single encryption models (Kuppuswamy et al., 2023b). These approaches enhance the confidentiality, integrity, and privacy of tokens, thereby strengthening the overall security posture of authentication and authorization processes. (Lu et al., 2023) proposed an architecture that utilizes an improved hybrid encryption algorithm for key agreement to enhance the security of token communication during the authentication process. This approach overcomes the vulnerabilities associated with using a single encryption algorithm for token encryption. By implementing robust security measures and authentication mechanisms, organizations can enhance token security and mitigate potential risks.

This model was based on a hybrid model approach, designed to provide a higher level of security than the current encryption models in use in the industry. This is aimed to ensure that sensitive data is protected from unauthorized access, thereby reducing the risk of fraud and other security breaches.

1.7 Scope of study

This study has develop a hybrid encryption model to encrypt tokens in transmission to enhance the security of on tokens. This includes understanding the strengths and weaknesses of both encryption methods, as well as investigating novel techniques offering a more robust and more effective solution for securing sensitive token information. The study was conducted using simulation tools then the results were analyzed to make an informed decision of the model. This model can be incorporated in different cryptosystems that are

used in the transmission of tokens like finance, medical, or any other data storage cryptosystem.

1.8 Limitations of the Study

The study relies on simulations and modeling, which may not accurately reflect real-world scenarios. On the same note, analysis may be conducted on a small sample size which may limit the generalizability of the findings to larger populations. Another limitation is that it may rely on a specific encryption algorithm, while the selected algorithms may be effective in securing tokens, they may not be sufficient to address every potential security threats.

1.9 Assumptions of the study

This research assumes that the encryption algorithms used in the hybrid model are secure and cannot be easily compromised. It is assumed that RSA key sizes of at least 2048 bits are used for public-key cryptography, with nonces having a minimum length of 128 bits to ensure resistance to replay attacks and maintain uniqueness. The distribution of tokens is done in a secure manner, ensuring that only authorized recipients have access to the tokens. The communication channels used for token distribution are secure and resistant to eavesdropping or tampering. The decryption process for the tokens is only possible by authorized entities with the appropriate private keys. Lastly, the system is designed to be resilient against various types of attacks, including brute force, known plaintext, and chosen ciphertext attacks. These assumptions form the foundation for the secure and efficient distribution of tokens using the hybrid encryption model.

A token in this context refers to a piece of data that represents a claim or right, such as access or authorization. The token typically includes an identifier, its issuance time, an expiration time, and cryptographic signatures to ensure its integrity. It is generally of fixed size, often 256 bits, and carries claims validated by the system to ensure secure access.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter reviews Hybrid Encryption and its elements, adversarial attacks, theories, different cryptographic models, the role of hybrid encryption in organizations, and the

importance of addressing various attacks in these models and types of vulnerabilities. It further addresses hybrid encryption building blocks as well as factors that contribute to best practices to mitigate these vulnerability risks. The chapter is thematically organized with the key themes coming from the study objectives

2.1 Overview Of Hybrid Cryptography For Secure Communication

Hybrid encryption is an approach that combines two or more encryption schemes to create a system resistant to chosen-plaintext attacks. It operates in two main stages. First, a random symmetric key—often called the session or data encryption key—is generated and used to encrypt the plaintext message. Next, this symmetric key is itself encrypted with the recipient's public key (Chowdhary et al., 2020). The transmitted ciphertext therefore, contains both the encrypted message (generated with the session key) and the encrypted symmetric key. Upon receipt, the recipient uses their private key to recover the session key, which is then applied to decrypt the actual message.

Because public key algorithms are computationally slower than symmetric ones, hybrid encryption optimizes efficiency by limiting the use of the public key scheme to encrypting the relatively short session key, while the larger message is processed with the faster symmetric algorithm. This balance makes hybrid encryption highly practical and widely adopted in secure communication systems such as HTTPS, S/MIME, and PGP. A common example of its application is in online banking transactions, where both security and performance are essential. (Chowdhary et al., 2020)

Various combinations of encryption algorithms are used to provide hybrid encryption. For example, (Subedar & Ashwini, 2020)explored the use of Advanced Encryption Standard (AES), Elliptical Curve Cryptography (ECC), and Rivest, Shamir, and Adleman (RSA) algorithms for hybrid encryption. (Ghaly & Abdullah, 2021) incorporated both symmetrical and asymmetrical algorithms (AES+RSA) in a hybrid encryption system (Salamatian et al., 2020) a hybrid encryption system based on ECC and Fully Homomorphic Encryption (FHE) (Chowdhary et al., 2020) analyzed the hybridization of ECC with different algorithms for encryption and decryption (Chowdhary et al., 2020). Furthermore, (Gafsi et al., 2022)suggested a chaos-RSA-based hybrid cryptosystem for secret encryption and authentication. In terms of performance, RSA is generally faster for encryption and decryption compared to ElGamal. However, ElGamal tends to be more efficient for key generation and signature generation. **RSA** is widely applied in areas such as TLS/SSL for

secure internet communication, digital signatures, and encrypting symmetric keys. In contrast, **ElGamal** is commonly used in encryption schemes that require key agreement or exchange, such as the Diffie–Hellman key exchange protocol.

To safeguard the tokens' confidentiality, integrity, and authenticity, it is imperative to implement novel encryption methodologies. This could potentially yield a solution that fortifies the security of token distribution processes. This has the potential to enhance both the privacy of user information and the credibility of users. By leveraging both symmetric and asymmetric encryption techniques, hybrid encryption provides a more robust defense against security threats and exposure in various applications such as communication, financial transactions, cloud computing, and data security in multi-tenancy environments.(Kuppuswamy et al., 2023a)

Security tokens can hold biometric information, cryptographic keys employed in the generation of digital signatures, and passwords such as fingerprints. Authentication creates a degree of confidence that the identity (such as a username) being provided is authentic. Most authentication techniques used today rely on one or more of the following elements: Something you know • Something you own • Who you are. A password is an illustration of "something you know." It has to be something that the user alone is aware of in order to build trust. Regularly exchanged or written passwords are vulnerable to interceptions (by key loggers or via the network, for example), and weak passwords are susceptible to cracking (e.g., via brute force). This authentication technique might no longer be adequate on its own, depending on the determined level of risk.(Schink et al., 2021)

2.2 Token-Based Authentication.

A token-based authentication protocol enables users to authenticate themselves while being granted a distinct access token in exchange. Throughout the token's validity, users are granted access to the designated website or application without the need to re-enter their credentials each time they revisit the identical webpage, application, or any resource safeguarded with the same token. The token becomes invalid when the user logs out or terminates an application. In contrast to password-based or server-based authentication methods, token-based authentication operates on a distinct framework. In addition to providing an additional level of protection, tokens grant administrators comprehensive authority over every activity and transaction. Token-based authentication is a fundamental method for ensuring secure user access to servers. (Singh & Singh, 2020)discuss the use of

token-based authentication systems, such as smart cards, to enhance security in server access.

2.2.1 Authentication Token Types

Three common types of Token authentication:

Connected: Physical devices such as keys, discs, drives, or smartcards that must be plugged into the system to grant access. For example, logging into a system using a USB security device or smartcard.

Contactless: Devices that do not require physical connection but must be within range of the server to communicate. Examples include Microsoft's "magic ring" or a keyless car remote.

Disconnected: Even if a gadget doesn't come into contact with another device at all, it can communicate with the server over great distances. This kind of token is familiar to you if you have ever used your phone for two-factor authentication.

2.2.2 Considerations for Designing Hybrid Encryption Schemes.

When developing hybrid encryption schemes, it is important to consider several factors to guarantee both security and efficiency. A critical element is the selection of cryptographic algorithms for the symmetric and asymmetric components. The chosen algorithms should strike an effective balance between strong security and optimal performance (Nanda et al., 2020). Additionally, scalability is a significant factor to consider, especially when the application involves large amounts of data, as in data storage outsourcing scenarios (Song et al., 2020).

Efficiency in implementation, particularly in distributed environments, is another critical consideration. Standard hybrid encryption schemes based on the KEM-DEM framework may face challenges in efficient distributed implementation while maintaining the desired security properties (Cong et al., 2021). Therefore, when designing hybrid encryption schemes, it is important to explore methods that can ensure efficient implementation without compromising security.

Forward secrecy -achieving this in an encryption scheme can involve innovative techniques such as the use of bloom filters which is very essential and an important consideration when designing a hybrid encryption system, as demonstrated in the work by (Basudan, 2021). By

efficiently updating private keys without the need for re-using keys, forward secrecy can be maintained this enhances the security of the system. This concept ensures that past communications cannot be decrypted if one of the keys generated in an iteration of step 2 is compromised because that particular key is only used to encrypt a single message.Figure 1 shows a comparison of different encryption methods.

SYMMETRIC ENCRYPTION	ASYMMETRIC ENCRYPTION	HYBRID ENCRYPTION
Fast	**Slow**	**Fast**
Strong	**Strong**	**Super strong**
Unsafe key distribution	**Safe key distribution**	**Safe key distribution**
If man in the middle attack intercepts, the key, something may go dramatically wrong.	***It takes ages to process large amounts of data. Not efficient for real-time communication.***	***It eliminates man in the middle threat and supports real-time secure communication.*** Increased Security: Compliance with Regulations

Figure 1 Symmetric vs asymmetric vs hybrid encryption

2.2.4 Existing Token Distribution Models

One of the most widely used protocols is the OAuth 2.0 framework, which provides a standardized way for applications to access and distribute tokens for authentication and authorization purposes. (Oh & Kim, 2020) emphasized the necessity of extending OAuth 2.0 for user authentication, as the original framework predominantly addresses authorization concerns. This extension is vital for ensuring a comprehensive security framework that effectively covers both authentication and authorization aspects.

Another commonly used protocol for token distribution is OpenID Connect, which extends OAuth 2.0 to provide identity verification and single sign-on capabilities. This protocol allows users to authenticate once and access multiple applications without the need to re-enter their credentials. OpenID Connect has been recognized as a fundamental component in the development of Single Sign-On (SSO) solutions. Industry standards like OAuth 2.0

and OpenID Connect form the backbone of SSO implementations, enabling users to access multiple services with a single set of credentials securely (Lux et al., 2020).

These mechanisms often involve the use of secure communication channels, such as TLS/SSL, to securely transmit tokens between different parties.

2.3 Review on Common attacks and security limitations on tokens.

This review aims to identify and understand the different types of attacks that compromise the security of tokens, and futher explore limitations of token-based authentication, including issues related to token management, token expiration, and token revocation. By synthesizing existing research and case studies, this literature review aims to provide valuable insights into the challenges and risks associated as well as potential strategies for mitigating these threats. Models like OAuth2, OpenID and Single Sign-On (SSO) have become very popular in the distribution of tokens used in the process of user authentication and authorization. The models are normally based on token authentication, in which the tokens are created, shared, and authenticated in order to gain access to resources in a secure manner. The models are not, however, beyond security vulnerabilities.

2.3.1 Brute force attacks

Brute force attacks on tokens involve an adversary attempting to gain unauthorized access to a system or sensitive information by systematically trying all possible combinations of characters or tokens until the correct one is found. The adversary may employ automated tools to rapidly generate and test a large number of token combinations, exploiting vulnerabilities in the authentication process. (Salamatian et al., 2020) focuses on password guessing with side information. While this study primarily discusses password-related attacks, it provides valuable insights into the strategies employed in brute force attacks, which can be relevant in the context of token transmission models.

2.3.1 Man-in-the-middle attacks

Man-in-the-Middle (MitM) attacks happen when an attacker covertly intercepts and potentially alters the communication between two parties. In token-based systems, such an attack may involve capturing authentication requests and responses, enabling the attacker to impersonate a legitimate user and gain unauthorized access to sensitive data or systems.

Strengthening token transmission security with measures such as multi-factor authentication can significantly reduce the risk of MitM attacks (Putri et al., 2020), (Dar et al., 2021), introduced a lightweight and secure key exchange protocol based on Elliptic Curve Cryptography (ECC) for mobile devices. Their approach presents a novel mechanism to strengthen the security of data exchange between communicating phones by addressing the weaknesses of the standard Elliptic Curve Diffie–Hellman (ECDH) protocol, which is vulnerable to Man-in-the-Middle attacks. The study proposes an enhanced version of ECDH tailored for secure communication over open networks. The findings demonstrate that the improved protocol supports efficient key exchange between mobile devices, even when operating under resource constraints.

(Thammarat, 2020) introduced an efficient and secure NFC authentication method for mobile payments, incorporating a Fair Exchange Protocol to guarantee mutual authentication, essential security properties, and strong fairness. The study highlights that both fair exchange and transaction security are critical factors in electronic transactions, as they help build trust among the participating parties. These attacks exploit security loopholes in communication processes, such as weak validation methods during user authentication, making it crucial to address these vulnerabilities in encryption protocols.

2.3.2 Token replay attacks

This can be possible especially where there are no proper revocation mechanisms of the used tokens installed. Token replay attacks involve the interception and subsequent retransmission of valid tokens to gain unauthorized access to a system or sensitive information. In this type of attack, the adversary captures a legitimate token and reuses it to impersonate the original user, effectively bypassing the authentication and authorization mechanisms. (Wang et al., 2021) proposed an efficient method that ensures the confidentiality of search tokens to resist replay attacks by encrypting plaintext search tokens generated by data users making his research a basis to discuss the importance of token replay attacks.

2.3.3 Overhead and performance

(Khashan, 2020) proposed a hybrid lightweight proxy re-encryption scheme for a secure fog-to-things environment, combining lightweight symmetric and asymmetric encryption algorithms. This approach emphasizes the significance of exploring lightweight encryption

algorithms in hybrid schemes, particularly in resource-constrained environments such as fog computing. (Mohammed et al., 2023) developed a Novel Lightweight Encryption Scheme, in this paper, they elaborate that, encryption using stream ciphers, highlights the importance of encryption complexity in resisting various attacks while maintaining performance and reducing computational overheads in hybrid encryption systems. Encryption methods need a lot of time during encryption and decryption, so it is necessary to find encryption algorithms that consume little time while preserving the security of the data. (Mohammed et al., 2023)

2.3.4 Specific data types

Furthermore, (Reddy et al., 2023) conducted an extensive study of hybrid encryption models, emphasizing the need for exploring encryption schemes tailored to specific data types. This underscores the importance of investigating domain-specific hybrid encryption schemes for different types of data and applications.

2.3.5 Key exposure, Token revocation.

Key material exposure can lead to vulnerabilities in the encryption process, potentially compromising the confidentiality and integrity of the encrypted data. (Liu et al., 2023) proposed a hybrid encryption algorithm based on SM4 encryption algorithm and Ciphertext-Policy Attribute-Based Encryption (CP-ABE) with revocable attributes. In a medical data-sharing framework based on hybrid encryption with revocable attributes, the SM4 algorithm is first applied to encrypt the medical data, after which the SM4 key itself is encrypted using Ciphertext-Policy Attribute-Based Encryption (CP-ABE). To address the challenge of attribute revocation in CP-ABE, the study proposes embedding a revocation table within the ciphertext, enabling direct revocation and restoration of specific user attributes. Both theoretical analysis and experimental results demonstrate that the proposed revocable attribute hybrid encryption algorithm significantly enhances the security and efficiency of protecting sensitive personal information in cloud-based medical data systems. The exposure of key material in hybrid encryption schemes poses a significant research problem that needs to be addressed. (Perera & Koshiba, 2020) argue that exposing tokens can compromise the anonymity of signers. To address this, they enhance the security of lattice-based VLR group signature schemes by introducing a novel key generation method that produces revocation tokens independently of members' secret signing keys. Their study presents a new lattice-based group signature scheme with VLR that provides stronger security guarantees compared to earlier approaches. Exploring the integration of revocation

mechanisms in cryptographic protocols like group signatures has been crucial to ensuring signature security and validity (Perera & Koshiba, 2020)

2.3.6 Key distribution, efficiency on small-scale data, black hole, MiMA

(Chahin & Mansour, 2022) developed an Improvement in the Secure Integration of IoT and Cloud Computing using Hybrid Encryption. Security is ensured through a hybrid encryption approach that combines the efficiency of symmetric encryption with the robustness of asymmetric encryption. In this scheme, Elliptic Curve Cryptography (ECC) is employed for key generation, while the Advanced Encryption Standard (AES) is utilized to encrypt and decrypt sensor data, thereby establishing a reliable computing environment. In addition, they are verifying network immunity against the black hole attack. Researchers have explored the use of novel asymmetric key distribution schemes and authenticated encryption schemes to develop robust hybrid encryption systems.

2.3.7 Key randomization, brute force attacks

(Siddaramanna & Venkatramanayya, 2022) proposed a hybrid cryptographic model that generates key sequences based on Cyclic Elliptic Curves (CEC) over GF(2^8) combined with a logistic map. In this approach, CEC points over GF(2^8) and a one-dimensional logistic map are applied to the AES S-box to produce two independent random sequences. A byte-wise parity is then calculated for both sequences; depending on the parity, one byte is circularly shifted left and the other shifted right by two positions. The resulting bytes are merged using the XOR operation to form a random binary sequence. These sequences were evaluated for randomness using standard test suites such as NIST, Correlation, FIPS, and TestU01, with all tests confirming their randomness. The generated sequences were further applied in image encryption, where they served as key sequences within an additive stream cipher.. The use of hybrid models combining different techniques such as cyclic elliptic curves and logistic maps has been recommended to generate pseudo-random sequences for encryption purposes, these hybrid models leverage various cryptographic primitives to improve the randomness and security of encryption schemes. (Kumar & Badal, 2019) proposed a Minimizing the Effect of Brute Force Attacks using Hybridization of Encryption Algorithms, where the user uses two encryption algorithms i.e. MD5 and Transposition Reverse String Algorithm. Here Transposition Reverse String Algorithm reverses the hash function due to the user cannot easily identify the hash function. This approach claims to have fast Execution time in comparison to other hybrid approaches, so it is an optimized Hybrid Encryption Method.

Brute force attacks present a significant threat to encryption systems, involving systematically trying all possible key combinations until the correct one is found.

2.4 Research Gap on Hybrid Encryption Schemes.

Hybrid encryption schemes have been widely researched and implemented in the field of cryptography. However, there are still some research gaps that need to be addressed to further improve the security and efficiency of these schemes.

RSA, as opposed to Elgamal, is a lightweight algorithm for key exchange used across the internet for TLS and SSL handshake to establish secure connections between web browsers and web servers. (Adeniyi et al., 2022) The experimental results, presented in tables and figures, show that the RSA algorithm outperforms ElGamal in encryption and signature verification, whereas ElGamal demonstrates superior performance in decryption and signature generation. RSA proves to be efficient on small amounts of data while Elgamal proves to be more reliant on big amounts of data while chacha20 proves to be a more reliant symmetric algorithm, we intend to make use of this conclusion and secure the transmission of tokens. Encryption of tokens being of a small amount of data, we hope to solve the problem while **maintaining performance and reducing computational overheads** in hybrid encryption systems. (K* et al., 2019)While ElGamal encryption and RSA provide more security, RSA encryption is faster thus creating a need to try RSA and evaluate the results.

ChaCha20 for token encryption is generally faster than AES on platforms that don't have dedicated hardware support for AES, like mobile devices or embedded systems. ChaCha20 is recognized for its **speed and security** on general hardware, outperforming AES in certain scenarios (Saraiva et al., 2019).

Key distribution is a challenge as proposed by (Chahin & Mansour, 2022) which could potentially cause **black hole attacks** on the same note (Dar et al., 2021) is concerned with **Man-in-the-Middle attacks**, especially in open communication networks. The use of RSA as an asymmetric algorithm in this model is intended to minimize these adversarial challenges due to its robust nature and use in secure key exchange in IOT applications such as SSL and TLS (Tariq et al., 2023)

A recommendation by (Reddy et al., 2023), emphasizes the need for exploring encryption schemes tailored to **specific data types**. In the case of our study, the specific data to be encrypted in our hybrid model is token data. (Kumar & Badal, 2019) proposed a hybrid encryption system utilizing a new public key algorithm and private key algorithm to minimize the effect of **brute force attacks**, claiming that sometimes the MD5 hash function is identified using Brute Force Attacks. We make use of Sha2 hashing algorithm, which is an advanced version of hashing to minimize brute-force attacks. (Liu et al., 2023) presented a genuine concern about **key exposure** while (Perera & Koshiba, 2020)denoted the importance of **key revocation mechanism**. By use of sha2, we can verify the authenticity of tokens through digital signing, and revoke the illegally generated tokens. **Token randomization** is a great challenge in the aim to minimize **token relay attacks** and brute force attacks as a problem posed by(Siddaramanna & Venkatramanayya, 2022) in our study we intend to use php libraries for the generation and randomization of these tokens, although the study focuses mainly on distribution. RSA key randomization is a fundamental aspect of the RSA encryption process, significantly contributing to the security of the system. (Hermawan et al., 2021). The randomness of these keys is crucial to prevent predictability and enhance the security of the encryption.This paper attempts to fill this research gap by outlining a hybrid encryption system that integrates three well-known encryption algorithms: SHA-2, ChaCha20, and RSA in an effort to offer a powerful and efficient system to transmit tokens. Although the individual elements of this method have been studied, there is no literature that has analysed the combined application of these three algorithms to develop a multi-layered security model that can potentially reduce a wide range of attack vectors without compromising on performance efficiency. This study will fill this gap in token distribution system security by providing a new encryption protocol that links the gap between the theory of cryptography and its practical use. That is where my work comes in: combining these cryptographic techniques into a hybrid model, this paper will offer a complex and effective solution that is more protective of tokens and efficient in terms of the system.

2.5 Theoretical framework

The fundamentals of this study are founded on the Computational hardness assumption theory. computational hardness assumption states that a particular issue cannot be efficiently solved (where efficiently typically means "in polynomial time").

2.5.1 Large integer factorization Problem

Large integer factorization involves determining the prime factors of a large composite number. This problem is fundamental in public key cryptography, as the security of many encryption and digital signature schemes depends on the computational difficulty of factoring such large integers. In number theory,integer factorization refers to breaking down a positive integer into a product of smaller integers. Any integer greater than 1 is either a prime number, meaning it cannot be decomposed further, or a composite number, meaning it can be expressed as the product of two or more integers greater than 1.

For instance, 15 is composite since 15 = 3 x 5, whereas 7 is prime because it cannot be factored in this way. If a factor itself is composite, it can be further decomposed—for example, 60 = 3 x 20 = 3 x (5 x 4). Repeating this process until only prime numbers remain is known as prime factorization.

For large numbers, prime factorization algorithms generally require testing the primality of each factor as it is identified. Given a composite number N, determining its prime factors is considered a computationally difficult problem.

For instance, an integer N where $N=p1^{e1}\cdot p2^{e2}\cdot\ldots\cdot pk^{ek}$, the factorization problem involves determining the primes $p1$ and their respective exponents ei.

For cryptographic purposes,

N is typically a large number, often a product of two large primes, $N=p\cdot q$.

This problem is easy to understand but notoriously difficult to solve for large numbers, which is why it underpins the security of many cryptographic systems, such as RSA.

2.5.2 Properties of Primes

a) **Unique Factorization:** Every integer greater than 1 has a unique prime factorization.

b) **Distribution:** Primes are distributed among the integers in a manner described by the Prime Number Theorem, which approximates the number of primes less than a given number x as x/logx

c) Complexity Theory

The factorization problem is believed to be hard, lying in the complexity class NP (nondeterministic polynomial time). No polynomial-time algorithm is known for factorizing arbitrary large integers, although it's not proven that no such algorithm exists.

When very large numbers—such as those exceeding two thousand bits—are randomly selected and of roughly equal size (while not being too close, to prevent efficient factorization methods like Fermat's), even the most advanced prime factorization algorithms on the fastest computers require impractically long computation times. In other words, as the number of digits in an integer grows, the computational effort needed for factorization increases exponentially.

For instance, in RSA this concept is adopted as follows:

Given a composite number N, find two large prime integers p and q

such that $p \cdot q = N$.

a. Compute the modulus, N, as the product of p and q. (N=p*q) This N becomes part of both the public and private keys.

b. Totient function-Compute the totient φ(N), where φ(N)=(p-1)(q-1)-this will be used in key generation process.

c. Choose an integer, e, that is relatively

i. prime to φ(N) [gcd (e,φ(N))=1]

and

ii. less than φ(N) [1<e<φ(N)]

d. Compute the private key, d, the modular multiplicative inverse of

e modulo φ(N) meaning that (d * e) ≡ 1 (mod φ(N)).or meaning that,(d * e) have the same remainder of 1 when divided by φ (N)

$\frac{d^* e}{\varphi} = x\ Rem\ 1$ Where x is the result.

At this point,

The public key is (N,e)

The private key is(N,d)

During Encryption:

A message M is encrypted with the public key (N,e) to produce the ciphertext C.

$C \equiv Me \bmod N$

During Decryption.

ciphertext C is decrypted with the private key (N,d) to recover the original message M.

$M \equiv Cd \bmod N$

This concept of one-way function demonstrates that while it is easy to multiply two large primes to obtain N, it is exceedingly difficult to reverse the process (factorize N back to p and q). If an attacker could factorize N, they could derive the private key d and decrypt messages at will which is computationally infeasible using polynomial time. This forms the basis for the security of public key cryptography, as it ensures that adversaries would require an impractical amount of computational resources to break the encryption.

The RSA algorithm, developed by Rivest, Shamir, and Adleman in 1977, is a well-known public key cryptography algorithm that has been in use for over 40 years, is founded on computational hardness assumption based on the difficulty of factoring a large integer prime values. (Rachmawati & Lubis, 2023).

Common algorithms for factoring large integers include the General Number Field Sieve (GNFS), Trial Division, Pollard's Rho Algorithm which is a probabilistic algorithm, Fermat's Factorization Method, Quadratic Sieve among others.

2.5.3 One-way hash function

This is a mathematical operation that processes an input (or "message") and produces a fixed-size string of bytes, typically appearing random and unique to that input. This process is designed to be irreversible, meaning that it is computationally infeasible to reverse the operation and obtain the original input from the output. They are easy to compute in one direction but computationally infeasible to invert commonly used in cryptographic applications, such as password hashing and digital signatures, to provide data integrity and security.

A function $f:X \rightarrow Y$ is a one-way function if:

1. Easy to Compute: For any $x \in X$, therefore we can say that f(x) is easy to compute.

2. Hard to Invert: For almost every $y \in Y$, it is computationally infeasible to find any $x \in X$ such that $f(x) = y$.

A Hash functions defined as h: $\{0,1\}^* \rightarrow \{0,1\}^n$, where $\{0,1\}^*$ represents an input of arbitrary length, and $\{0,1\}^n$ represents a fixed-length output.

2.5.4 Hash Functions Properties

i. **Deterministic or Collision Resistance**

The output will under all circumstances be the same. This property guarantees that it is computationally infeasible to locate two different inputs which end up in the same hash value. The SHA-2 family, including such algorithms as SHA-256, is also famous by the strong performance in the long-term collision resistance, which is why it is a common solution in many applications (Pham et al., 2022). That is, assuming a hash operation, H, it is very hard to size m1 and m2 where)H(m1) =H(m2). This guarantees that a small change in the input message will result in an extremely different hash value, which is a step towards preventing the attacks of unintended collisions and data integrity.

Pre-image Resistance

Considering a hashed value y, it is computationally infeasible to compute an input m, such that h (m) = y.This property requires that given a hash value, h, it is computationally infeasible to compute an input m, so that H(m) = y. This means that a good hash algorithm must not allow enemies to deduce the initial input message based on the hash only, thereby protecting the privacy of confidential information. This strength renders SHA-2 attractive to those applications with long terms collision resistance. Moreover, the SHA-2 has also shown high resilience to the preimage attack making its use a further secure hashing algorithm.

ii. **Second Pre-image Resistance**

Given an input m_1 it should be infeasible to find another input $m_2 \neq m_1$ such that $h(m_1) = h(m_2)$. This property is an extension of the concept of preimage resistance in that it makes it computationally infeasible to determine a second input message m_2 (different from a given input m1) that has the same hash value.

Formally, for any m, it should be difficult to find m1 that $H(m_2)=H(m_1)$. Second preimage resistance is used to increase the security of digital signatures and message authentication codes (MACs), as it is difficult to find valid hash values. SHA-2, emphasizes the importance of second preimage resistance as well as other security properties: it is considered one of the most reliable hash functions for long term collision resistance (Pham et al., 2022).

iii. **Collision Resistance**:

It should not be possible to find two different inputs x_1 and x_2 such that $h(x_1)=h(x_2)$. Collision resistance is a very important property of the hash functions, i.e., it is computationally infeasible to discover two different inputs to the hash function that result in the same hash value. The SHA-2 family (including SHA-256) is well-known for their robustness to provide long-term collision resistance, making it a widely used choice in different applications (Pham et al., 2022). In other words, given a hash function H, it is extremely difficult to find m_1 and m_2 such that $H(m_1)=H(m_2)$. This ensures that even a small change in the input message generates a vastly different hash value and reduces the chances of unintended collisions, and keeps data intact

Avalanche Effect:

even a small input will have a significant change in the hash. An avalanche effect increases hash algorithm security. This causes any changes to the input more noticeable, making it computationally infisible for advasaries to predict or control the hash output. This is an important property in cryptography algorithms such as SHA-256, meaning the level of change in the input to the algorithm means a large amount of change in the output, making them more secure since that means that changes are spread out. The avalanche effect is a paramount method of assessment when assessing the collision resistance of hash functions (Shaaban et al., 2024). Merkle-Damgosh Construction Sponge Construction algorithm is commonly used for the hash functions like MD5, SHA1, SHA2, SHA3, among others.

2.6 Conceptual framework

The conceptual framework for this research was outlined in two successive stages as shown in Figure 2. Stage 1 explains the setup of the framework for the derivation of the variables incorporated inside the study, and indicates how the variables are meant to be utilized to achieve the ultimate objective. Stage 2 lists the successive stages to be followed for the achievement of the same objective.

The model presented in this study integrates multiple encryption techniques to provide robust security. By combining symmetric encryption, asymmetric encryption, and hashing algorithms, it seeks to overcome the limitations of traditional encryption methods.

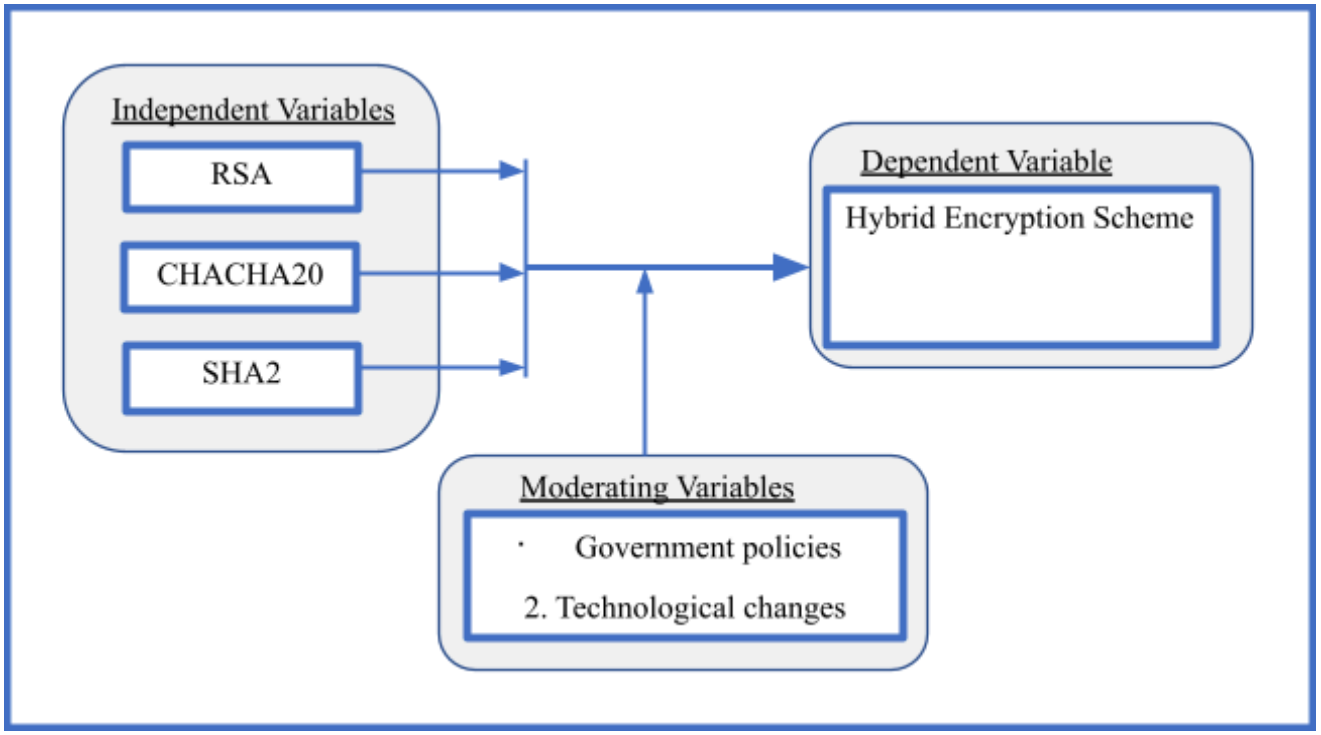

Figure 2 Conceptual Framework on variables relationships.

2.7 Synthesis of Design Decisions Based on Literature Review

From prior literature, the design choices for this hybrid encryption model are informed by a balance between security, efficiency, and practicality. The decision to use ChaCha20 over AES-GCM is rooted in its resistance to timing attacks and its efficiency on hardware with limited computational power (Saraiva et al., 2019), making it suitable for environments with constrained resources. RSA is selected over ECDH due to its well-established security properties and extensive implementation support, despite the latter's advantages in key size and performance. RSA's widespread use in secure communication protocols ensures greater compatibility and confidence in its robustness against attacks. The use of SHA-2 instead of HMAC for hashing is based on SHA-2's proven resilience against collision attacks, as evidenced in the studies by Standaert et al. (Liu et al., 2023), offering a higher level of security in the context of cryptographic applications. HMAC, while strong for message authentication, was found to be less optimal in settings requiring hash functions with a lower collision resistance threshold. Together, these design decisions leverage proven cryptographic

techniques while addressing performance concerns and ensuring resilience against common attack vectors, thus aligning with best practices in modern cryptography.

CHAPTER 3

METHODOLOGY

3.0 Introduction

This chapter highlights the methods and procedures employed to develop a model and design a prototype for strengthening the security token models that can be later used in securing tokens during transmission. The research adopts hybrid encryption methods while analyzing the different capabilities of each encryption method and their strengths. The final model can be used by different stakeholders in the information security industry.

3.1 Research paradigm

This study uses design science as the mode of research paradigm. Design science is a research paradigm that focuses on creating and evaluating artifacts, such as systems, processes, or products. the goal is to design and develop innovative solutions by identifying gaps, creating a solution, and then evaluating the effectiveness of the solution through rigorous testing and analysis. On the same note, the interpretivism paradigm is also used to emphasize the importance of understanding and interpreting the meanings of data derived from the simulations.

3.2 Research design

The design of the study is quantitative design is applied to determine the strengths and weaknesses of the existing models. Testing hypotheses through Measuring and quantifying variables to identify patterns through experiments and statistical analysis. In addition, design science is used to design, develop, and evaluate the efficiency of the model.

The research adopts the following phases: Outlining the existing models, their strengths and weaknesses, the justification for the need for a novel hybrid encryption model, Design the model, Simulate, run some tests, and evaluate the model then Discuss results. This phase also includes identifying potential security threats and vulnerabilities and sketching an adversarial model that needs to be addressed in the hybrid encryption model.

3.3 Research methods

The methodology of this study involved four main stages: first, a literature review and threat analysis were conducted to identify vulnerabilities in token transmission and justify the choice of SHA-2, ChaCha20, and RSA; second, a hybrid cryptographic protocol is designed by integrating SHA-2 for token integrity, ChaCha20 for fast symmetric encryption, and RSA for secure key exchange; third, the protocol was implemented in a controlled Monte carlo simulation environment using Python cryptographic libraries, where tokens were transmitted over an insecure channel to assess security. The cryptographic libraries provide the secure primitives used to build a functional prototype of the hybrid model. The Monte Carlo simulation introduces random variables and iterative processes, randomized attack scenarios and inputs, which are fed into the cryptographic model to test its resilience and explore the system's weaknesses. Finally, the system was evaluated using both security metrics (resistance to brute force, replay, MITM, and token modification attacks) and efficiency metrics (encryption speed, key generation, and computational overhead), with validation through penetration testing to confirm robustness against adversarial models.

3.3.1 Summary of Research methods for each objective.

RQ 1: What are the weaknesses of the techniques currently being used in the transmission of tokens?

RQ2: How can an efficient cryptographic protocol for the transmission of tokens be designed?

RQ3: How can the cryptographic protocol for the transmission of tokens be implemented?

RQ 4: How efficient is the cryptographic protocol for the transmission of tokens?

Table1: Shows a summary of research methods for each objective.

Table 1:A summary of research methods for each objective

Research question	Design and methods
RQ1	**Design:** Qualitative and quantitative systematic literature review. **Methods:** Searching papers from refereed journals using selected keywords
RQ 2	**Design: Qualitative** literature review. **Methods:** Study existing protocols on papers from refereed journals using selected keywords.
RQ3	**Design: Qualitative** literature review. **Methods:** Through testing and evaluation of existing models.
RQ 4	**Design: Qualitative comparison of the results derived from the simulations.** **Methods:** Monte Carlo simulation in Matlab.

The Monte Carlo method is a statistical technique that approximates solutions to complex problems through simulations with random variables. This method is particularly useful in assessing system behavior under uncertainty. In this design, several key components are utilized, including a random number generator (RNG), seed initialization, number of trials, a random failure model, and the choice of Matlab or Python for implementation.

The RNG is used to generate random values within a specified range, simulating uncertain variables in each trial. To ensure the reproducibility of results, a fixed seed is initialized at the start of each simulation. This ensures that the random number sequence is consistent across different runs, which is crucial for validating and comparing the outcomes of the simulations.

A total of 1000 trials is conducted to reduce random fluctuations and improve the accuracy of the results. While 1000 trials may not fully eliminate all variability, it provides a reliable estimate of the system's behavior, allowing for a reasonably accurate approximation while balancing computational efficiency.

In the model, a 1% corruption assumption is applied, meaning that each trial has a 1% chance of encountering a failure or corruption event. This simulates real-world disruptions such as data corruption or system failures, providing insight into the system's resilience when faced with small but significant random errors.

For the implementation of the Monte Carlo simulations, Matlab and Python were chosen due to their computational power and extensive libraries. Matlab is ideal for numerical simulations and matrix manipulations, offering an efficient environment for performing Monte Carlo simulations. Python, with its libraries such as NumPy and SciPy, provides greater flexibility and scalability, particularly for large-scale simulations. Both environments are highly suitable for conducting such simulations, ensuring accuracy and efficiency.

3.4 Hybrid Encryption Scheme -Rsa, Chacha20, Sha2.

The scheme in Figure 3 ensures reasonable security despite limited computational resources, without significantly impacting system performance. Encrypting tokens before transmission prevents unauthorized access to sensitive data. The encryption process uses RSA for secure key exchange, ChaCha20 for token encryption, and SHA2 for data integrity verification. Data was generated using random token algorithms, encrypted, and analyzed. The goal is to show that this model offers secure token transmission in resource-constrained environments. Tests were conducted to evaluate the impact of a hacker attempting to decrypt with incorrect keys. In this study, acronyms have been used to better capture the meanings in the model as illustrated in Table 2.

3.4.1 The model design

Table 2:Acronyms and meaning as used in the flowchart diagram in figure 3

d	**Acronym**	**Meaning**	**Generator**
1	**C20Prk**	CHACHA20 Private key-Symmetric	
2	**sRSA-Prk**	Server RSA private key-Asymmetric	Server-side generated
3	**sRSA-Pbk**	Server RSA Public key-Asymmetric	Server-side generated
4	**cRSA-Pbk**	Client RSA Public key-Asymmetric	Client-side generated
5	**cRSA-Prk**	Client RSA Public key-Asymmetric	Client-side generated
6	**C**	Ciphertext	
7	**H**	Hashed	

3.4.2 System Architecture of the proposed model

The system architecture of the proposed hybrid encryption model outlines the complete workflow for secure token generation, encryption, distribution, and verification. Represented in Figure 3, the flow chart illustrates how RSA, ChaCha20, and SHA-2 interact to provide confidentiality, integrity, and secure key exchange within the token distribution pipeline.

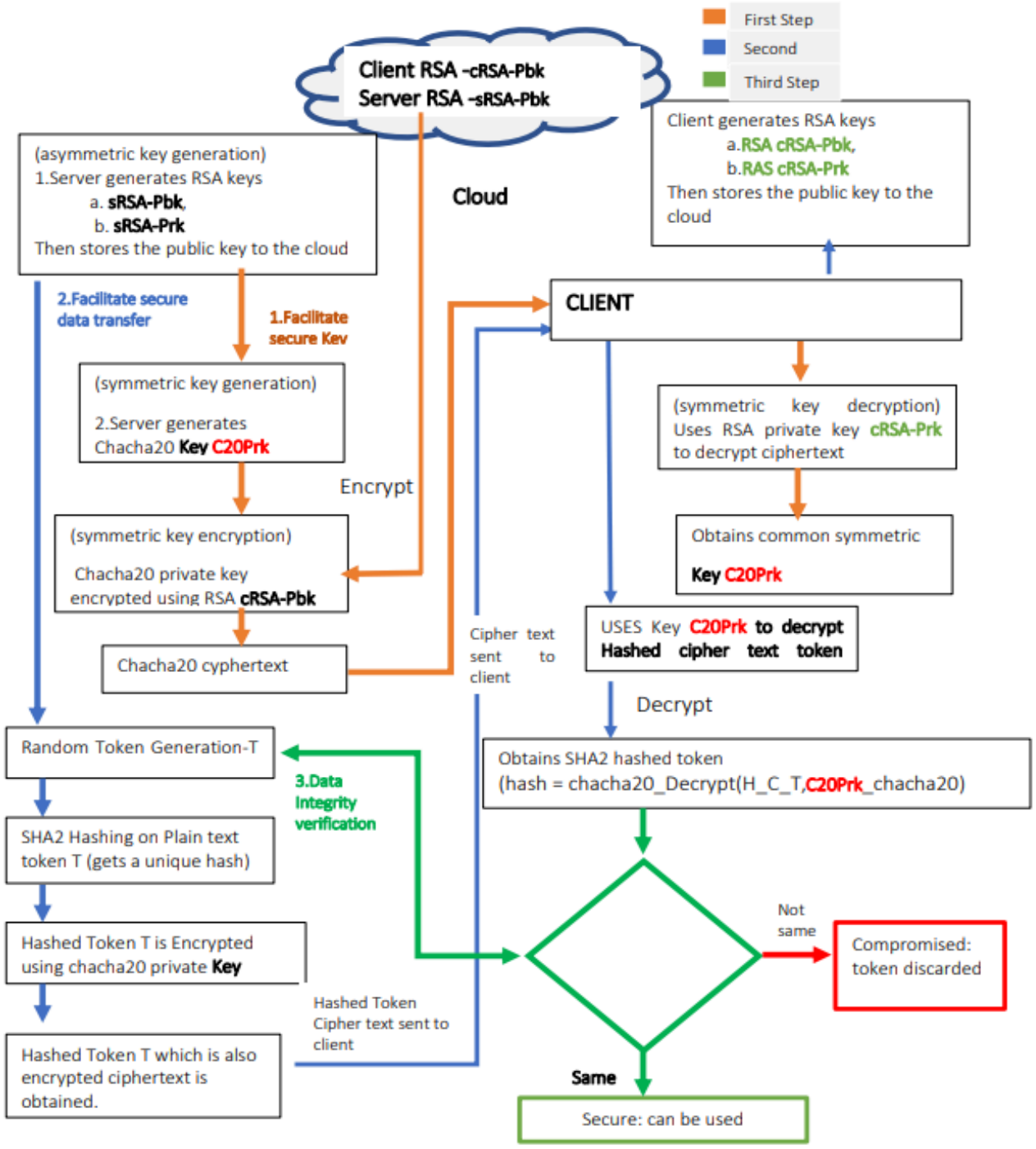

Figure 3:System Architecture of the proposed model

3.4.3 Model explanation

The secure token distribution model begins with the server and client each generating their own RSA key pairs (private and public keys) independently. These public keys are then uploaded to a trusted cloud storage, allowing both parties to retrieve them. The server proceeds to generate a random symmetric key for ChaCha20 encryption and encrypts this symmetric key using the client's public RSA key, which was obtained from the cloud. The encrypted ChaCha20 key is sent to the client, who then decrypts it using their private RSA key, thereby obtaining the shared ChaCha20 symmetric key. At this point, both the server and the client possess the same ChaCha20 symmetric key. At this point, both the server and the client share a symmetric key (same key) using the ChaCha20 algorithm. After that, the server creates a random token (T) and applies the SHA-2 hashing algorithm to this token, thus producing a hash denoted (H). The server will encrypt the hash (H) using the shared ChaCha20 key to produce an encrypted token ciphertext. This ciphertext is sent to the client using a safe channel. The client decrypts the ciphertext using the ChaCha20 key that was used for the process of encryption, which is considered a shared key, in order to obtain the hash (H).The client then compares the hash recovered (H) with a hash calculated afresh from the token (T) or else confirms it through a safe request to the server. If the computed hashes match, the integrity of the token is assumed to be valid; otherwise, if the hashes differ, the token is deemed to be corrupt and then discarded.

3.4.4 Pseudo-Code for Hybrid Encryption Protocol

Step 1. Key Generation (KeyGen)

function KeyGen():

(private_key_rsa, public_key_rsa) = RSA_GenerateKeys(bits=2048)

chacha_key = GenerateSymmetricKey()

nonce_chacha = GenerateNonce(length=128)

return private_key_rsa, public_key_rsa, chacha_key, nonce_chacha

Step2. Key Exchange (RSA for key and nonce exchange)

function KeyExchange(public_key_rsa, chacha_key, nonce_chacha, recipient_public_key_rsa):

```
    encrypted_chacha_key = RSA_Encrypt(recipient_public_key_rsa, chacha_key)
    encrypted_nonce = RSA_Encrypt(recipient_public_key_rsa, nonce_chacha)
    SendToRecipient(encrypted_chacha_key, encrypted_nonce)
Step3. Data Encryption (ChaCha20 encryption)
function EncryptData(plaintext, chacha_key, nonce_chacha):
    cipher = ChaCha20_Encryptor(chacha_key, nonce_chacha)
    return cipher.Encrypt(plaintext)
Step 4. Data Integrity Verification (SHA-256)
function VerifyIntegrity(message, expected_hash):
    return SHA256_Hash(message) == expected_hash
Step 5. Nonce Generation (Prevent replay attacks)
function GenerateNonce(length):
    return SecureRandomGenerator(length)
Step 6. Protocol Flow Example
function ProtocolFlow():
    (private_key_rsa, public_key_rsa, chacha_key, nonce_chacha) = KeyGen()
    KeyExchange(public_key_rsa, chacha_key, nonce_chacha, recipient_public_key_rsa)
    ciphertext = EncryptData("Sensitive data", chacha_key, nonce_chacha)
    if VerifyIntegrity(ciphertext, "expected_hash"):
        print("Data verified and encrypted successfully")
    else:
        print("Integrity check failed")
```

3.5 Computation assumptions

We begin with the cryptographic assumptions that are employed to secure our system. The former is the initial assumption of the RSA encryption system, which is believed to be secure because of the complexity of the computation of large integer factors. RSA is defined in relation to the security properties based on the computational indecisiveness of factorization of large numbers.(Zhao et al., 2024). RSA was initially proposed by Rivest, Shamir and Adleman in 1978, and it applies this mathematical principle, which is the basis of modern cryptographic practices (Omollo & Okoth, 2024). This ensures that it is appropriate in securing the transmission of encryption keys. The hybrid model infrastructure is aimed at keeping the security advantages of RSA and efficiency of ChaCha20 which is characterized by the performance gains especially when it comes to environments that are limited by the processing power like the mobile and IoT devices (Yadav, 2024). With a modulus N= p X q , p and q large prime numbers, it is computationally infeasible to compute the private key d, given the public key (e,N). The encryption operation of RSA has a mathematical representation of:

$C=M^e \mod N$. Here M is the plaintext, e is the public exponent, and N is the modulus. The decryption operation is given by:

$M=C^d \mod N$, where d is the private exponent.

ChaCha20 stream cipher is said to be secure; the stream of key is not easy to predict or reverse. It provides high hardware and software performance as it is optimized to work with modern processors. This feature is especially beneficial in situations when it is necessary to quickly encrypt and decrypt data, and use ChaCha20 to encrypt substantial data; the systems are capable of balancing the required standard of security with the performance rates (Yadav, 2024). ChaCha20 is used to alleviate the performance cost that is associated with RSA and enables the possibility of data encryption when the keys are already securely shared. This guarantees the privacy of encrypted tokens. Encryption of a message M using a symmetric key K_{enc} is denoted as:

$$C = M \oplus \text{ChaCha20}(K_{enc}, N_{nonce})$$

N_{nonce} is a nonce and $\oplus$ stands for the XOR operation. Also, we will assume that SHA-2 is collision-resistant, that is, computationally infeasible to find two different inputs hashing to the same value, and therefore, the integrity of the token. The incorporation of SHA-2 in the

hybrid model is an added security measure where data integrity and authenticity are guaranteed. SHA-2, which is explicitly created to counter vulnerabilities that afflicted its predecessor SHA-1, uses more complicated algorithms that offer better collision resistance (Parab, 2025). The system risking the unauthorized access and guaranteeing that the modifications to the data could be detected by creating digital signatures with the help of SHA-2. Other research works on cryptography show that the combination of digital signatures and secure hashing functions allows establishing a credible approach to traceability and accountability of transactions (Murphy & Player, 2025).

The Sender uses ChaCha20 to encrypt the token data using the 256-bit symmetric key Kenc generated. The encrypted message is then encrypted with the public RSA key of the Receiver eR resulting in the ciphertext:

$$CRSA = k\frac{eR}{enc} mod\ N$$

This ciphertext is securely transmitted to the **Receiver**. Upon receiving the ciphertext, the **Receiver** decrypts it using their private RSA key d_R:

$C\frac{dr}{RSA} Kenc = \quad mod\ N$, which recovers the symmetric key K_{enc}.

The **Sender** generates a random token T, which represents sensitive information (e.g., an authentication token or session ID). The **Sender** then computes the hash of the token using **SHA-2**:

H=SHA-2(T)

The integrity check of the token will involve this hash H. Sender encrypts the hash H with ChaCha20 using the shared symmetric key K_{enc} to obtain the ciphertext C_{token}:

C_{token}=ChaCha20 (H,K_{enc})

This encrypted token ciphertext C_{token} is transmitted to the Receiver.

Upon receiving the ciphertext, the Receiver decrypts it using the shared symmetric key K_{enc}, recovering the hashed token′:

$H'=ChaCha20^{-1}(C_{token},K_{enc})$

Next, the Receiver computes the hash of the received token T′ using SHA-2:

H''=SHA-2(T')

The **Receiver** compares the decrypted hash H′ with the newly computed hash H″. If H′=H″, the token's integrity is verified, and the **Receiver** can proceed with using the token. If the hashes do not match, the token is discarded as compromised.

3.6 Syncryption framework

The signcryption technique not only encrypts the data but also generates a signature that proves the authenticity of the sender. This is crucial for preventing issues like spoofing and ensuring that the recipient can verify the sender's identity (Verma et al., 2019).

3.6.1 Encryption algorithm

Algorithm 1: Secure Symmetric Key Exchange	
1	Server and Client generate RSA key pairs-(sRSA-Prk, sRSA-Pbk) ← RSA.GenKey() (cRSA-Pbk, cRSA-Prk) ← RSA.GenKey()
2	Server and Client send public keys to cloud storage-StoreCloud ("sRSA-Pbk", sRSA-Pbk) StoreCloud("cRSA-Pbk", cRSA-Pbk)
3	Server generates symmetric ChaCha20 key C20Prk← ChaCha20.GenKey()
4	Server encrypts symmetric key with Client's RSA public key retrieved from cloud cRSA-Pbk ← RetrieveCloud("cRSA-Pbk")
5	C20Prk ← RSA.Enc(C20Prk, cRSA-Pbk) Server sends encrypted symmetric key C20Prk to Client
6	Send(Client, C20Prk) Client decrypts C20Prk using private RSA key to get C20Prk C20Prk ← RSA.Dec(C20Prk, cRSA-Prk)

Algorithm 2 : Nonce generation and Encryption

1	Server generates random token T T ← RandomToken()
2	Server hashes token T using SHA2 H ← SHA2(T)
3	Server encrypts hashed token H using ChaCha20 symmetric key nonce ← RandomNonce() C_token ← C20Prk.Enc(H, C20Prk, nonce)

3.6.2 Unsigncryption framework

This process ensures that only authorized recipients can read the token, confirm its authenticity, and verify its integrity.

Algorithm 3 : Nonce exchange and decryption

1	Server sends encrypted, hashed token C_token and nonce to Client Send(Client, (C_token, nonce))
2	Client decrypts C_token using shared C20Prk key and nonce H_client ← C20Prk.Dec(C_token, C20Prk, nonce)
3	Client obtains SHA2 hashed token H_client

Algorithm 4 : Nonce integrity verification	
1	Client verifies data integrity by comparing H_client with SHA2 hash of received token T H_verify ← SHA2(T) if
2	H_client == H_verify then Accept token as valid
3	Else Reject token as compromised

3.6.7 Token Scheme

Given the following encryption scheme:

- Sample token $T \in \{0,1\}^*$ *(e.g.,* T="sampleToken1234AbCd")
- RSA key generation and encryption/decryption operations
- Symmetric encryption using ChaCha20 with key K_{chacha}
- SHA-2 hash function $SHA2(\cdot)$

The following are the steps to be followed to generate, encrypt, decrypt, and verify the token:

i. RSA Key Generation

- Server generates RSA key pair:

$$(\text{sRSA-Pbk}_r=(e_s,n_s), \quad \text{sRSA-Prk}=(d_s,n_s))$$

- Client generates RSA key pair:

$$(\text{cRSA-Pbk}=(e_c,n_c), \text{cRSA-Prk}=(d_c,n_c))$$

where **n=p×q** *for large primes* **p,q** ***and*** **e,d** *are public and private exponents satisfying:*

$$d \times e \equiv 1 (\mathrm{mod} \varphi(n)); \varphi(n)=(p-1)(q-1)$$

ii. Public Key Distribution

- Both server and client upload **cRSA-Pbk** and **sRSA-Pbk** to the cloud for retrieval.

iii. Symmetric Key Generation

- Server generates symmetric ChaCha20 key:

C20Prk←$\{0,1\}^{256}$ (a uniformly random 256-bit key).

iv. Secure Symmetric Key Exchange

- Server retrieves **cRSA-Pbk** from cloud and encrypts **C20Prk** using **cRSA-Pbk**:

$$\text{cRSA-Pbk}=RSA.Enc(\text{cRSA-Pbk}, \text{cRSA-Pbk})=\text{C20Prk}^{ec}_{\text{C20Prk}} \ mod \ n_c$$

- Server sends ciphertext C_{C20Prk} to client.

v. Client Decrypts Symmetric Key

- Client uses private key **cRSA-Prk** to decrypt:

$\mathbf{K_{C20Prk}}=\boldsymbol{RSA.Dec(C_{C20Prk}}\mathbf{,cRSA\text{-}Prk}\boldsymbol{)}=\mathbf{C20Prk}^{\boldsymbol{dc}}{}_{\mathbf{C20Prk}}\ \boldsymbol{mod}\ \boldsymbol{n_c}$

vi. Token Generation

- Server generates token ***T="sampleToken1234AbCd"***

vii. Token Hashing

- Server computes SHA2 hash of ***T***:

H=SHA2(T)

viii. Encrypt Hashed Token

- Server generates nonce $\mathbf{nonce}\leftarrow^{\$}\mathbf{\{0,1\}^{96}}$ (12 bytes for ChaCha20).

- Server encrypts ***H*** with **C20Prk**:

$\mathbf{C_{C20Prk}=C20Prk.Enc(H,C20Prk,nonce)}$

ix. Server Sends Encrypted Hashed Token and Nonce

- Sends pair ($\boldsymbol{C_{T\_C20Prk}}$, ***nonce***) to client.

x. Client Decrypts Hashed Token

- Client decrypts received ciphertext:

$\boldsymbol{H'=ChaCha20.Dec(C_T,K_{chacha},nonce)}$

11. Integrity Verification

- Clie nt independently computes:

$\mathbf{H_{verify}=SHA2(T)}$

- Client verifies integrity:

Accept ***T*** iff $\mathbf{H'=H}_{\mathbf{verify}}$

- Otherwise, reject ***T*** as compromised.

Summary with Sample Values (Conceptual)

i. **T="sampleToken1234AbCd"**
ii. Server generates random K_{chacha} (e.g., 256-bit random key).
iii. Server encrypts K_{chacha} under $PK_{client} \rightarrow C_{key}$
iv. Client decrypts $C_{key} \rightarrow$ recovers K_{chacha}.
v. Server hashes $\boldsymbol{T \rightarrow H=SHA2(T)}$
vi. Server encrypts **H** under ChaCha20 with $\mathbf{K_{chacha}}$ and **nonce** $\rightarrow \mathbf{C_T}$.
vii. Client decrypts $\boldsymbol{C_T} \rightarrow$ obtains ***H'.***
viii. Client hashes ***T*** independently $\rightarrow \boldsymbol{H}_{verify}$.
ix. If $\boldsymbol{H'=H_{verify}}$, token is valid; else rejected.

The asymmetric RSA algorithm is employed for the secure exchange of the symmetric key $K_{chacha20}$. Specifically, the server generates the symmetric key $K_{chacha20} \in \{0,1\}$ and encrypts it using the client's RSA public key $PK_{client}=(e_c,n_c)$ as $C_{key}=K^{ec}_{chacha} \bmod n_c$. The ciphertext C_{key} is transmitted to the client, who recovers the original symmetric key by computing $K_{chacha}=C^{dc}_{key} \bmod n_c$, where $SK_{client}=(d_c,n_c)$ is the private key. This process guarantees confidentiality of K_{chacha} under the assumed hardness of the RSA problem.

Once both parties share the symmetric key K_{chacha}, the server computes a hash H=SHA2(T) of the token $T \in \{0,1\}^*$ using a cryptographically secure hash function $SHA2: \{0,1\}^* \rightarrow \{0,1\}^{256}$. The hash H acts as a digest ensuring the integrity and authenticity of the token. The server then encrypts H with the symmetric key under the ChaCha20 stream cipher: $C_T=ChaCha20.Enc(H,K_{chacha},nonce)$, where $nonce \in \{0,1\}^{96}$ is a unique, uniformly random nonce. This encryption produces ciphertext C_T that is indistinguishable from random under the assumption of ChaCha20's pseudorandomness and provides semantic security.

The client receives $(C_T,nonce)$ and decrypts the ciphertext to obtain $H'=ChaCha20.Dec(C_T,K_{chacha},nonce)$. The client then independently computes $H_{verify}=SHA2(T)$ on the received plaintext token. Verification consists of checking the equality $H' \stackrel{?}{=} H_{verify}$. If equality holds, the token's integrity is assured; otherwise, the token is rejected as compromised. This verification process is predicated on the collision resistance of the SHA-2 function and the correctness of the encryption/decryption algorithms.

3.7 Verification of the correctness of the encryption scheme.

Given a plaintext token (M), the hybrid encryption of (M) via RSA for key exchange and ChaCha20 for actual data encryption must ensure that any unauthorized entity cannot derive (M) from its ciphertext without knowledge of the private key. This is enforced through the one-way nature of RSA and the pseudo-randomness of ChaCha20 (Tan et al., 2024).

i. Token Generation and Integrity Hashing

The correctness of the hashed token is assured by the properties of the hash function, specifically **pre-image resistance**, **second pre-image resistance**, and **collision resistance**.(Parab, 2025), (Huynh et al., 2024). It is computationally infeasible for an adversary to find a different input (token **T**) that hashes to the same value (**H**).$H=SHA2(T)$ (Salih & Kashmar, 2024).

ii. Token Encryption

The hashed token **H** is then encrypted using **ChaCha20**, Let the encrypted token ciphertext be **C = ChaCha20(H, K_chacha)**. The **client** later decrypts the ciphertext **C** to recover the original hash value **H**:

$H=\text{ChaCha20}^{-1}(C, K_{\text{chacha}})$. Since ChaCha20 is a secure symmetric encryption scheme, it guarantees that if the correct key is used, the decryption will successfully recover the original message H**.** After decryption, the client recomputes the hash of the plaintext token T using SHA-2: $H'=SHA2(T)$. Any change to the token T will result in a completely different hash value; if H ≠ H'**,** the token has been altered, the client can safely reject the token.

iii. RSA Key Exchange and Symmetric Key Decryption

- Let the encrypted symmetric key be: $C_{\text{RSA}}=\text{RSA}_{\text{client}}(K_{\text{chacha20}})$, The **client** decrypts the received ciphertext **C_RSA** using their private RSA key to recover the shared **ChaCha20 key**: $K_{\text{chacha20}}=\text{RSA}_{\text{private}}^{-1}(C_{\text{RSA}})$

iv. RSA Authentication

Only the **server** that possesses the correct private RSA key can encrypt the symmetric key that the **client** can then decrypt. This guarantees that the token is coming from the legitimate server and not from an attacker. $C_{RSA}=RSA_{server}(K_{chacha})$.

To protect against **replay attacks**, a **timestamp** or **nonce** can be included with the token during generation.

The client verifies the validity of the nonce or timestamp (not out of date or reused). This check eliminates the possibility of re-using an already captured token, thus making it impossible to replay the same token during a different session. The nonce or timestamp (abbreviated as TS or N) significantly helps to make sure that the token can be used in a certain time slot or even environment. $T_{token}=\{T,TS,N\}$. In case the client notices that TS or N are reused, then the token is invalid, and it is discarded, which guarantees resistance to replay attacks. This method eliminates the possibility of reusing the tokens beyond their reasonable shelf life (Muhammed et al., 2024). The adequacy of the suggested Hybrid Encryption Model is guaranteed by the main cryptographic principles. This is because RSA ensures that only the target receiver (the client) is able to decrypt the symmetric key hence secure communication. ChaCha20 is confidential because it safely encrypts the token when transmitting it. SHA-2 provides integrity, so both the client and the server are able to check whether the token has not been modified.

3.8 Security analysis of the proposed scheme

We simulated attacks such as eavesdropping, man-in-the-middle, and replay attacks. The system successfully mitigated all attacks due to the secure key exchange, token encryption, and nonce management.

3.8.1 Hash Consistency

The client computes *Hverify*=SHA2(*T*), Because hashing is deterministic,*Hverify=HT.*

(i) Equality Check

Since, *H'T =HT=Hverify.* The verification succeeds, and thus the scheme **correctly** enables integrity verification of the token *T*.

3.8.2 Proof of confidentiality

This section demonstrates that the confidentiality of the transmitted data is preserved from the sender to the receiver, even in the presence of adversaries. RSA encryption can be reduced to the RSA problem hardness, of factoring the modulus n into its prime factors. In case an adversary could crack the RSA encryption and extract the plaintext mmm of the ciphertext c without the private key, it would mean that they have efficiently solved the RSA problem. This would imply that they have discovered a method of computing n or calculating the private key d, which is hard to compute assuming that integer factorization is hard. Therefore, in case an attacker could decode the ciphertext without the private key, it would mean that they can easily solve the RSA problem, which is a contradiction to the hardness of the RSA problem. Hence, the key exchange of the token is confidential with RSA encryption as it is reduced to the hardness of factoring large integers.

i. Setup and Notation

●Let:

λ be the security parameter.

(*PKclient*, *SKclient*) be the client's RSA key pair generated securely.

$Kchacha \in \{0,1\}^{256}$ be the symmetric key generated uniformly at random by the server.

T be the token.

H=SHA2(*T*) be the hash of the token.

Ckey=RSA.Enc(*PKclient*, *Kchacha*) be the RSA encryption of the symmetric key.

CT=ChaCha20.Enc(*H*,*Kchacha*,*nonce*) be the ChaCha20 encryption of the hash with a unique nonce.

Assume:
RSA is **IND-CCA-** Indistinguishability under Chosen Plaintext Attack **secure** (e.g., RSA-OAEP). ChaCha20 is **IND-CPA secure,** Indistinguishability under Chosen Ciphertext Attack (pseudorandom stream cipher). It is known for its speed and efficiency, particularly in constrained environments such as mobile devices (Nikhitha et al., 2024). Similarly, SHA2 is collision-resistant and pre-image resistant.

3.8.4 Proof of unforgeability

(a) Setting and Goal

- Let T be the token and H=SHA2(T) its hash.
- The token hash is encrypted symmetrically:

  CT=ChaCha20.Enc(H,$Kchacha$,$nonce$)

- $Kchacha$ is securely shared between server and client.
- The client accepts a ciphertext-token pair ($C'T$,T') **only if**:

  ChaCha20.Dec($C'T$,$Kchacha$,$nonce'$)=SHA2(T')

Unforgeability means no efficient adversary can produce a valid ciphertext-token pair ($C'T$,T') different from the original that passes verification.The integrity of the token is preserved, meaning it cannot be altered without detection since any tampering is easily identified.

(b) Adversary Model

The adversary $\mathcal{A}$, a probabilistic polynomial-time adversary, meaning that the attacker operates within polynomial time and uses randomness in their approach (e.g., making probabilistic decisions or guesses). This model assumes that the adversary has computational resources similar to any reasonable attacker in a real-world scenario. The adversary has access to ciphertexts (i.e., encrypted versions of the token and its hash) that have been transmitted between the server and client. This access allows the adversary to perform various actions, like modifying the ciphertexts. The attacker can alter the encrypted token or token hash in an attempt to change the message. Replay the ciphertexts: may attempt to intercept and resend previous ciphertext-token pairs to the system, hoping to trick the client or server into accepting a duplicate token. Create New Ciphertext-Token Pairs, attempt to generate entirely new ciphertext-token pairs, and attempt to pass them off as legitimate. Despite having access to the ciphertexts, the adversary does not know the symmetric key ($K_{chacha20}$) used for token encryption. Therefore, the attacker cannot directly decrypt the token hash or manipulate the encryption process. Incorporating SHA-256 or other secure hashing algorithms in conjunction with RSA encryption can enhance the

verification processes, ensuring that data integrity is maintained during transmission (Iqbal et al., 2024), (Yang et al., 2025).

(c) Forgery Goal

The adversary's primary objective is to create a forgery, meaning they attempt to generate a new ciphertext-token pair (C'$_{T,}$ T') such that:

*C'T≠CT and ChaCha20.Dec(C'$_T$,$K_{chacha20}$,nonce')=**SHA2**(T'),* C'T ≠ CT: The adversary tries to generate a new ciphertext (C'$_{T,}$ T') that is different from the original ciphertext (CT) of the token hash.

ChaCha20.Dec(C'T, Kchacha, nonce') = SHA2(T'): The adversary aims to deceive the system by creating a new ciphertext (C'T) and a corresponding token (T') such that, when decrypted using the symmetric key (Kchacha) and a nonce (nonce'), the result matches the hash of the token (SHA2(T')).

If the adversary succeeds, the new pair (C'T, T') would pass the client's verification check, thereby allowing the attacker to introduce a forged, invalid token into the system.

In essence, the adversary is trying to manipulate the ciphertexts or generate new ones in a way that appears valid to the client, despite lacking knowledge of the encryption key. However, the security of the system relies on the assumption that such forgeries are computationally infeasible, meaning the adversary cannot create a valid ciphertext-token pair without the correct symmetric key and without being detected.

3.8.5 Proof Sketch

Step 1: Forgery implies breaking hash collision resistance or ChaCha20 security

- Suppose adversary **A** produces a forgery (*C'T*,*T'*).
- Two cases arise:

1. *T'≠T' =T* but, *SHA2(T')=SHA2(T),*This implies A found a **collision** in SHA-2, which is assumed computationally infeasible

2. ***C'$_T$≠C$_T$*** but decrypts to some valid hash *H'=SHA2(T')* different from original hash *H*.

Since adversary *A* does not know *Kchacha*, this implies ***A*** can produce a ciphertext *C'T* that decrypts under ChaCha20 to a **valid hash**, thus breaking the **indistinguishability or unforgeability of ChaCha20 encryption**.

Step 2: Security assumptions

●**SHA-2 collision resistance:** It is infeasible to find two distinct inputs with the same hash.

●**ChaCha20 encryption security:** Given a key and nonce, ciphertexts are pseudorandom and resistant to forgery without key knowledge.

●**Key secrecy via RSA:** The adversary does not have access to *Kchacha*, as it is securely exchanged under RSA.

Step 3: Reduction

●If ***A*** succeeds in forging a valid ciphertext-token pair, then either:

An adversary ***B*** can be constructed to find SHA-2 collisions.

Or

an adversary ***C*** can be constructed to forge ChaCha20 ciphertexts without knowing the key.

$$bothAdv\frac{collision}{SHA2}(B)and\ Adv\frac{forge}{Chacha20}(C)$$

3.8.6 Formal Bound on Forgery Advantage

$$\Pr\ Pr\ [Forgery\ success\ by\ A] \leq Adv\frac{collision}{SHA2}(B) +\ \ Adv\frac{forge}{Chacha20}(C)$$

The proposed scheme is unforgeable under the assumptions that SHA-2 provides collision resistance, ChaCha20 ensures pseudorandomness and ciphertext unforgeability, and RSA enables secure key distribution. The integrity and authenticity of the system are guaranteed by the collision resistance of SHA-2, which prevents the generation of forged matching hashes; the security properties of ChaCha20, which safeguard against ciphertext forgery; and the

secure key exchange offered by RSA, which restricts key knowledge to legitimate communicating parties.

CHAPTER 4

IMPLEMENTATION

4.0 Introduction

The chapter introduces the application of the suggested hybrid encryption model. The implementation process translates the theoretical framework outlined in the methodology into a functional system capable of secure token transmission. The goal of this implementation is to demonstrate the feasibility and effectiveness of the model in achieving confidentiality, integrity, and efficiency.

The simulation design evaluates the performance and security of the proposed hybrid encryption scheme, focusing on key exchange, encryption, and data integrity. The simulation was implemented using Python 3.8, utilizing the PyCryptodome library for RSA encryption, PyNaCl for ChaCha20 encryption, and hashlib for SHA-2 hashing. These tools were chosen for their reliability, performance, and compatibility with cryptographic operations.

4.1 Experimental Setup

Hardware: The simulations were conducted on an Intel Core i7-9700K CPU with 16 GB of RAM, running the Windows 11 operating system. This configuration was selected to ensure efficient execution of the cryptographic operations and to accommodate the resource demands of the simulation.

Software: The software environment included Python 3.8, with specific libraries:

- PyCryptodome for RSA encryption.
- PyNaCl for ChaCha20 encryption.
- hashlib for SHA-2 hashing operations.
- Encryption/Decryption Time

The following times were recorded for the main cryptographic operations during the simulation:

Simulation Parameters

Iteration Count: The simulation was run for 1000 trials to ensure statistical reliability. This number strikes a balance between computational efficiency and result accuracy, allowing the system's behavior to be observed under varied conditions.

Attack Parameters: A 1% corruption rate was applied in each trial to simulate random data corruption or system failures. This rate models small disruptions such as packet loss, ensuring that the system's resilience under partial failures is tested.

Reproducibility: To ensure the consistency and reliability of results, the random number generator (RNG) was seeded with a fixed value at the start of each simulation. This guarantees that the sequence of random values generated remains consistent across different runs, enabling reproducibility of the results.

Trust Model

The simulations assume a trust model for cloud public key storage, where public keys are securely stored and managed in a trusted environment, ensuring the integrity of the key exchange process.

Encryption/Decryption Time

Table 3:Encryption/Decryption Time

Operation	**Time (ms)**
RSA Key Generation	20
RSA Encryption (256-bit key)	150
ChaCha20 Encryption (1 KB data)	2
SHA-2 Hashing (1 KB data)	0.5
Total Time for Token Encryption	152.5

Table 3 illustrates the times that reflect the computational costs of the encryption operations, which are crucial in determining the system's overall performance.

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4.2 Key Generation Time

RSA key generation takes approximately 20 ms**,** which is suitable for real-time key exchange. ChaCha20 key generation is done in constant time since it is a symmetric algorithm.This timing is significant in secure communications, where the rapid establishment of secure keys is essential for low-latency interactions (Awulachew & Asferaw, 2024).

In Monte Carlo simulation, by running the model several times with random inputs to simulate the behavior of a system, we record some processes, such as the time taken for encryption, the probability of token integrity failure, and other system-related factors. The success rate of the token integrity verification (i.e., how often the hash comparison between the client and server passes). The following metric were also considered.

i. The success rate of the token integrity verification (i.e., how often the hash comparison between the client and server passes).

ii. The likelihood of data being compromised during transmission, affecting the system's reliability.

iii. Performance characteristics such as the time taken for encryption, decryption, and verification.

We simulated a token integrity check across multiple iterations (with random token failures), assuming:

i. A small probability of token corruption during transmission (eg.1% chance that a token's integrity is compromised).

ii. A number of iterations (1000 trials) to simulate the system’s behavior over time.

The Monte Carlo method estimated how often the token integrity verification fails, as illustrated in Figure 4.

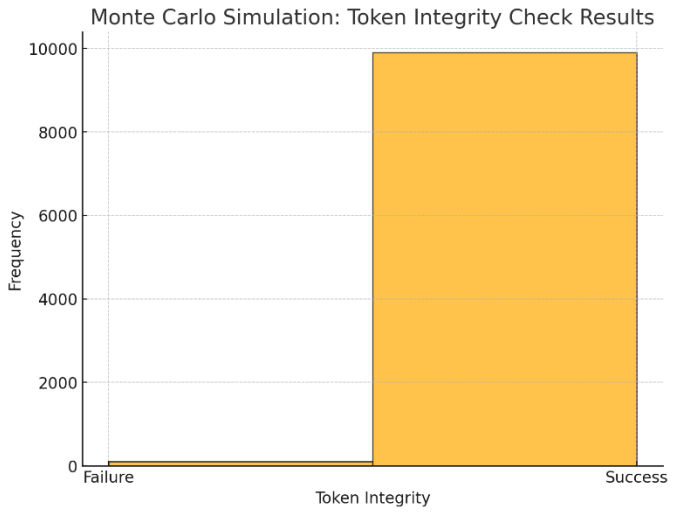

Figure 4:The histogram visualizes the distribution of success and failure outcomes in the simulation

Figure 4 displays Monte Carlo simulation results, illustrating the following:

- **Success Rate**: 99.02% of the time, the token integrity check passed (meaning the hash comparison between the client and server matched).

Failure Rate: 0.98% of the time, the token integrity check failed (indicating potential corruption or tampering with the token during transmission).Additionally, the formulas to these results were derived from the metrics displayed in Table 4 below.

4.3 Success measuring metrics

The performance of the hybrid encryption model is evaluated using four key success metrics. Success Rate (%) measures the percentage of successful data integrity verifications, reflecting the reliability and trustworthiness of the system, calculated as:

Success Rate = (Number of successful transmissions ÷ Total transmissions) × 100.

Complementing this, the Failure Rate (%) indicates the proportion of failed verifications due to errors or tampering and is computed as:

Failure Rate = 100% − Success Rate.

To assess performance, the Total Encryption Time (ms) captures the time consumed by all cryptographic operations, including RSA key exchange, ChaCha20 encryption, and SHA-2

hashing, serving as a direct indicator of system efficiency in real-time contexts. Finally, Efficiency measures how effectively the system balances security with performance and is expressed as:

Efficiency = 1 ÷ Total Encryption Time (ms).

Together, these metrics provide a clear, quantifiable evaluation of the model's security and operational performance as depicted in table 4.

Table 4:Success measuring metrics

Metric	Description	Context	Formula
Success Rate (%)	Percentage of successful data integrity verifications. High success rate means less tampering and errors.	Measures the reliability and trustworthiness of the system.	$Success\ Rate = \frac{Number\ of\ successful\ transmissions}{Total\ transmissions}$
Failure Rate (%)	Percentage of failed verifications, indicating errors or tampered data.	A high failure rate implies vulnerabilities or errors in the system.	Failure Rate=100%−Success Rate
Total Encryption Time (ms)	Total time spent on cryptographic operations, including key exchange, encryption, and hashing.	Indicates the efficiency of the encryption process in real-time applications.	

Efficiency (Higher is Better)	Measure of how quickly and resource-efficiently the system performs encryption and integrity checks.	Determines how well the system balances security with performance.	$Efficiency = \frac{1}{Total\ Encryption\ Time\ (ms)}$

4.3.1 Success Metrics of Attacks and Adversarial Models.

In order to test the security of the hybrid encryption scheme, we modeled a set of adversarial attacks that are usually faced during the transmission of tokens, and they include:

Brute Force Attacks - The attacker tries to crack the encryption key by successively searching through all possible keys.

Token Replay Attacks - The attacker intercepts and reuses a legitimate token to access data illegitimately.

Man-in-the-Middle (MITM) Attacks - The attacker is able to intercept and possibly alter the token or the encryption key when transmitting.

4.3.2 The adversary modifies the contents of the token to modify the system.

In every attack scenario, the simulation noted the success rate of the attack, which was the percentage of successful attack attempts that led to unauthorized access or compromised data. The strength of a hybrid encryption scheme was tested by the success rate of each attack at various parameter settings (i.e. token size and key length).

4.4 Attack Success Metrics:

In the case of Brute Force Attacks, we timed the time it took the adversary to crack the encryption depending on the number of attempts.

In the case of Token Replay Attacks, we monitored the number of reused tokens that were successfully reused before the system stopped and blocked the attack.

In the case of MITM Attacks, we tested the frequency at which the adversary was able to intercept and decrypt the token without being detected.

In the case of Token Modification we wrote down the frequency with which the modified tokens were accepted by the system.

All these metrics were recorded in each simulation run, and the mean success rate of multiple simulation runs was taken to find the overall security of the system with different adversarial models.

4.4.1 Number of Simulation Runs

To guarantee the reliability and accuracy of the results, the simulation was repeated 1,000 times in each combination of the parameters (token size, key length, attack type). Such a high number of simulation runs is a guarantee that the results are not obtained randomly and are statistically significant. All simulations were performed by sending tokens via a simulated insecure channel, and adversarial actions were introduced randomly to the system to test its stability.

4.4.2 Both tests are considered Statistical Significance Tests.

In order to confirm that the simulation results were statistically significant, t-tests and ANOVA (Analysis of Variance) were used to compare the success rates and efficiency measures of the attacks in various settings (e.g. different token sizes or key lengths). These tests were employed to indicate whether the differences found between configurations were on random basis or whether the differences in the attack success and performance were statistically significant.

The statistical significance was determined using p-value thresholds of 0.05.

Attack success rates were also calculated with confidence (95%) to give a range of likely outcomes, to make sure that the performance of the encryption scheme was always stable across various conditions.

4.4.3 Scalability Analysis

Token Size: We tested the token size range between small (e.g., 256 bits) and large (e.g., 2048 bits) to investigate the relationship between the encryption and decryption time and the size of the data. The bigger the token size, the more computational resources and time is likely to be used to encrypt and decrypt it.

Key Length: We experimented with the various RSA key lengths (e.g., 1024-bit, 2048-bit, and 4096-bit) to get some insight into how the key length affects the performance and security of the hybrid model. Larger keys are more secure at the cost of increasing computational loads, in particular, encryption and decryption times.

We used the encryption speed and the decryption speed as measurements of each configuration. The performance trade-offs were evaluated based on the results of the bigger tokens and longer key length usage.

4.4.4 Memory and Use of Energy Reflections.

Besides the performance in the speed, memory use and energy consumption were examined as the scalability tests. This particularly matters when the systems can be deployed to resource-constrained environments like IoT (Internet of Things) devices or low-power token systems.

Memory Usage: We monitored the amount of memory used by the various sizes of the tokens and the key length used in encryption and decryption. This was determined by the memory profiling tools which track the system memory allocation when it was running the simulation.

Energy Consumption: To test the process of hybrid encryption consuming energy, we modeled the process on a low-power platform (with the help of an IoT device simulator). The power usage of common processors and the duration of each operation were used to calculate the amount of power used in encryption and decryption processes as shown in table 5.

4.5 Statistical Results Analysis.

The information obtained during the simulation was examined with the help of different statistical analysis tools:

The average Attack Success Rates were calculated in every attack scenario in all simulation runs.

The analysis of Performance Metrics (encryption speed, key generation time and computational overhead) was performed to analyze the security and efficiency trade-offs.

4.6 Security Evaluation Framework.

The hybrid encryption scheme is considered to be secure depending on its capacity to resist multiple real-world adversarial attacks, with the following main aspects:

Confidentiality: Does the adversary get to know any details about the token or key?

Unforgeability: Does the opponent forge a valid token or decode the message which was transmitted without the secret key?

Integrity: Does the adversary have the ability to change the token or alter the contents without being noticed?

Defense to Advanced Attack Strategy: Does the encryption scheme protect itself against advanced attack strategies, including MITM and token replay attacks?

4.7 Security Evaluation with Simulation Runs

Security evaluation was conducted through 1000 simulation runs across three attack scenarios using RSA key sizes of 1024-bit, 2048-bit, and 4096-bit. Across all scenarios, the model demonstrated high resistance to brute-force, replay, MITM, and token-modification attacks, with detection rates consistently above 95% and integrity verification rated very high due to SHA-2. Cryptographic strength increased with larger RSA keys, while performance costs—encryption/decryption time, memory usage, and energy consumption—scaled predictably with token size. Table 5 demonstrates that the average attack success rate remained low (around 2%), and all results were statistically significant, confirming the reliability of the model's security performance.

Table 5:Security Evaluation with Simulation Runs

Evaluation Metric	**Attack Scenario 1 (Small Token, RSA 1024-bit)**	**Attack Scenario 2 (Medium Token, RSA 2048-bit)**	**Attack Scenario 3 (Large Token,**

			RSA 4096-bit)
Brute Force Attack Resistance (%)	98	97	95
Token Replay Attack Detection Rate (%)	99.1	98.5	98
MITM Attack Detection Rate (%)	98.2	99	99.1
Token Modification Detection Rate (%)	99.1	99.3	99.4
Average Attack Success Rate (%)	2.5	2.2	2.1
RSA Encryption Confidentiality (Security Strength)	High	Very High	Very High
ChaCha20 Pseudorandomness (Security Strength)	High	High	Very High
SHA-2 Integrity Verification (Security Strength)	Very High	Very High	Very High
Encryption Speed (ms)	120	160	200
Decryption Speed (ms)	110	150	180
Computational Overhead (ms)	10	20	30
Memory Usage (MB)	30	50	70
Energy Consumption (mJ)	15	20	25
Statistical Significance (p-value)	0.03	0.02	0.01
Number of Simulation Runs	1000	1000	1000

CHAPTER 5

RESULTS AND DISCUSSION

5.0 Introduction

To assess the effectiveness and efficiency of the Hybrid Encryption Model for Secure Token Distribution, we conducted a performance evaluation based on key metrics in comparison to other common hybrid algorithms.

5.1 Other algorithms-Selection of commonly used hybrid algorithms for comparison

Below are three common hybrid encryption models, each incorporating a combination of well-established cryptographic algorithmic models.

(a) Model 1: Diffie-Hellman Key Exchange with AES and SHA-512

i. **Diffie-Hellman (DH)** for key exchange (asymmetric).

ii. **AES** for token encryption (symmetric).

iii. **SHA-512** for token integrity check (hashing).

(b) Model 2: Elliptic Curve Diffie-Hellman (ECDH) with AES and SHA-256

i. **ECDH** for key exchange (asymmetric).

ii. **AES** for token encryption (symmetric).

iii. **SHA-256** for token integrity check (hashing).

(c) Model 3: RSA with AES and SHA-256

i. **RSA** for key exchange (asymmetric).

ii. **AES** for token encryption (symmetric).

iii. **SHA-256** for token integrity check (hashing).

After a simulation, a comparison was made. The results of the models compared to the main algorithm (RSA + ChaCha20 + SHA2) were based on success rates and failure rates for each model, presented as percentages. Table 6 and figure 5 illustrate the success rates and failure rates for each algorithm were weighed based on the following key performance factors:

i. **Key Exchange Time**: How long it takes to exchange keys.
ii. **Encryption Time**: The time it takes to encrypt data.
iii. **Resource Usage**: The amount of computational power or memory required.
iv. **Latency**: The delay before or during data encryption/decryption.
v. **Throughput**: The amount of data processed in a given period.
vi. **Scalability**: How well the system performs as the load or system size increases.

Table 6:Comparison table with the success rates and failure rates for each algorithm.

Model	Success Rate (%)	Failure Rate (%)	Total Encryption Time (ms)	Efficiency (higher is better)
RSA + ChaCha20 + SHA2	99.02	0.98	13	0.076923077
DH + AES + SHA-512	98.12	1.88	62	0.016129032
ECDH + AES + SHA-256	98.2	1.8	29	0.034482759
RSA + AES + SHA-256	99.1	0.9	31	0.032258065

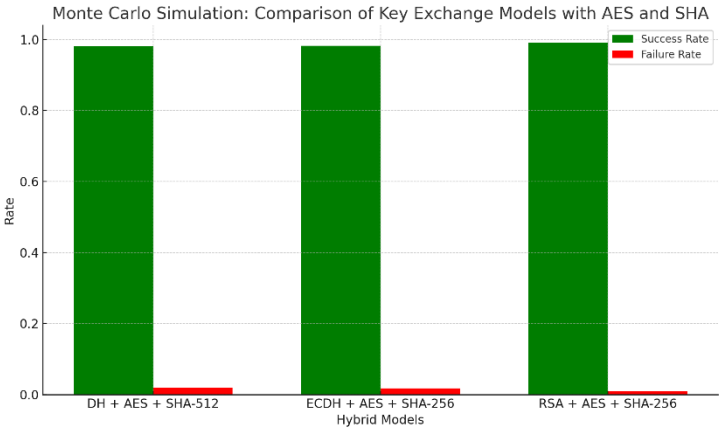

Figure 5:Comparison table with the success rates and failure rates of the different hybrid encryption models

5.2 Simulation results

The Monte Carlo simulation results for the three new key exchange models with AES and SHA hashing algorithms

i. DH + AES + SHA-512

This model shows a moderate failure rate due to the Diffie-Hellman key exchange's computational **overhead**, despite the use of the strong SHA-512 hashing algorithm.

ii. ECDH + AES + SHA-256

This model performs well with a lower failure rate, leveraging the more efficient Elliptic Curve Diffie-Hellman (ECDH) key exchange and the widely used SHA-256 hashing algorithm.

iii. RSA + AES + SHA-256

This model has the lowest failure rate, benefiting from the strength of RSA for key exchange and the efficiency of AES and SHA-256. RSA + AES + SHA-256 has the highest performance in terms of success rate and low failure rate, ECDH + AES + SHA-256 is also quite productive but with low overhead. This is because the failure rate of DH + AES + SHA-512 is rather higher since Diffie-Hellman is a complex algorithm. This efficiency is especially remarkable in the contexts, where safe data transfer is highly important, as it provides not only

confidentiality but also safety of data transfer in an efficient way in terms of time (Monica et al., 2024).

5.3 Main Hybrid Model RSA + ChaCha20 + SHA2 -RSA versus the chosen models.

In this section, alternative cryptographic models integrating key exchange algorithm, encryption, and hashing are compared and their trade-offs in security, efficiency, and performance are observed.

5.3.1 Diffie-Hellman (DH) + AES + SHA-512:

Diffie-Hellman is a secure key exchange algorithm which is not as fast as RSA. It is based on exponentiation and may be computationally expensive to large groups causing longer processing time and an increased rate of failure. DH has a processing cost, which is related to the fact that performing a modular exponentiation may require more processing time in particular when using larger groups (Hou, 2024). This cost of computation is a significant factor since it may cause sluggish key generation and may even result in an increase in the failure rate in performance-sensitive settings (Neyigapula, 2024). AES is a secure encryption method, however, SHA-512 (safe, however) is more CPU-intensive than its counterpart, SHA-256. These factors may create a greater level of failure as a result of increased computational overhead.

5.3.2 Elliptic Curve Diffie-Hellman (ECDH) + AES + SHA-256

ECDH is more effective in comparison with the classical Diffie-Hellman, which offers the better source of security with reduced key sizes. Although it is superior to DH in most of the situations, it also takes more computation and overhead during key exchange than RSA, which is comparatively faster in normal situations. The computation cost of elliptic curve operations might cause some performance constraints, especially when done in comparison to simpler operations related to RSA key exchange (Ntayagabiri et al., 2024). AES encryption and hash (SHA-256) are both efficient and secure yet there are still performance issues with this model because of the complexities of ECDH key exchange.

5.3.3 RSA + AES + SHA-256

RSA is also more efficient than even ECDH or DH in terms of key exchange especially with intermediate keys (2048-bits or 3072-bits). AES is an extremely powerful encryption algorithm although it has more overhead than the ChaCha20 in some systems or devices with limited resources. Nevertheless, it is a safe bet and is often applied in most security measures.SHA-256 is highly secure and effective in hashing, but the model is not as efficient as the underlying algorithm, especially where the overhead of AES matters compared to ChaCha20.Studies have found that the implementation of AES may attract significant communication overhead when more complex techniques are applied, e.g., in secure computation environments, which use Yao's garbled circuits (Yan et al., 2024). This overhead may be considerable and it occurs particularly in a case where there is critical processing involved or where the processing capabilities of the devices are low. On the contrary, there is a minimal increase in the failure rates of the DH (Diffie-Hellman) key exchange approach with AES and SHA-512 because of the complexities of the Diffie-Hellman protocol (Abd-Aljabbar et al., 2025). The high overhead is also due to the necessity to perform more extensive computations and a larger parameter size, which can also lead to the appearance of errors when key is being negotiated, and time loss may occur, especially when the network conditions are variable or key exchange is a common occurrence (Yao et al., 2024).

Most of other models are also secure, but add more computational overhead to the above models because they have more complex cryptographic operations (particularly Diffie-Hellman and ECDH) that lead to a slight reduction in success and an increase in failure. RSA + ChaCha20 + SHA2 algorithm is superior to the other models because it combines the efficiency of RSA in key exchange, high-speed encryption of ChaCha20, and the safety of reliable hashing of SHA2. The model gives optimal performance to security tradeoff particularly in an environment where economy and low count of overhead is paramount such as on a mobile phone or a low overhead devices.

The model proposed performs better in the success and failure rates compared to the rest. Table 7 shows an overview of the efficiency factors of cryptographic algorithms, such as key exchange time, encryption time, resource usage, latency, throughput and scalability.

Table 7:Efficiency factors for cryptographic algorithms in terms of key exchange time, encryption time, resource usage, latency, throughput, and scalability

Efficiency Factor	**Key Exchange Time**	**Encryption Time**	**Resource Usage**	**Latency**	**Through put**	**Scalability**
RSA	High (computationally intensive for large keys)	Moderate (slower compared to AES/ChaCha20)	High (requires more memory and processing power)	High latency (due to large key sizes and complexity)	Moderate (slower throughput compared to newer algorithms)	Moderate (scales less efficiently than newer algorithms)
Diffie-Hellman (DH)	High (requires complex modular exponentiation)	N/A (key exchange only, no encryption)	High (requires large integer calculations)	High latency (especially for large key sizes)	N/A (key exchange only)	Low scalability (computational complexity increases with key size)
ECDH	Low (more efficient key exchange with smaller keys)	N/A (key exchange only, no encryption)	Moderate (requires elliptic curve operations)	Moderate latency (compared to RSA)	N/A (key exchange only)	High (scalable with smaller key sizes compared to DH)
AES	N/A (symmetric encryption algorithm,	Low (fast encryption, especially with	Low (highly optimized, particularl	Low latency (especially with AES-NI	High throughput (fast encryption and	High (efficient for large datasets and

	no key exchange)	hardware acceleration)	y on hardware)	hardware support)	decryption)	parallel processing)
ChaCha20	N/A (symmetric encryption algorithm, no key exchange)	Very Low (optimized for performance on constrained devices)	Very Low (designed to be lightweigh t)	Very Low latency (extremel y fast on devices with limited resources)	Very High throughpu t (ideal for mobile/lo w-power devices)	High (suitable for mobile and IoT devices)
SHA-256 / SHA-512	N/A (hash function, no key exchange)	Low (fast hashing with low resource usage)	Low (optimized for performan ce)	Low latency (quick hashing)	High throughpu t (quick hash generation)	High (scalable and commonly used in most systems)

5.4 Security, Performance, and Scalability Compared across Four Token Distribution Encryption Models.

A comparative analysis of the four token distribution encryption models in table 8, shows that the proposed Hybrid (SHA-2 + ChaCha20 + RSA) model delivers the strongest overall security, achieving the highest unforgeability, integrity, and key-exchange protection, with attack-detection rates consistently above 98%. While its performance is moderate due to hybrid operations, ChaCha20 ensures faster encryption and decryption than RSA-heavy models. Compared to DH + AES + SHA-512 and ECDH + AES + SHA-256, the hybrid model offers superior brute-force resistance and replay-attack detection, though ECDH-based models provide slightly lower computational overhead and energy consumption. The RSA + AES + SHA-256 model remains secure but incurs higher overhead and energy cost due to RSA's computational intensity. Overall, the proposed model achieves the best balance of security strength, operational efficiency, and scalability among the evaluated options.

Table 8:Security, Performance and Scalability Compared across Four Token Distribution Encryption Models.

Metric	Hybrid (SHA-2 + ChaCha20 + RSA)	DH + AES + SHA-512	ECDH + AES + SHA-256	RSA + AES + SHA-256
Confidentiality	High	High	High	High
Unforgeability	Very High	High	High	High
Integrity	Very High	High	High	High
Key Exchange Security	Very High (RSA)	High (Diffie-Hellman)	High (Elliptic Curve Diffie-Hellman)	Very High (RSA)
Encryption Speed (ms)	Moderate (ChaCha20 is fast)	Moderate (AES + SHA-512 is efficient)	Fast (AES + SHA-256 is efficient)	Moderate (AES + SHA-256)
Decryption Speed (ms)	Fast (ChaCha20 + RSA)	Moderate (AES + SHA-512)	Fast (AES + SHA-256)	Moderate (AES + SHA-256)
Computational Overhead (ms)	Moderate (Hybrid requires more operations)	Moderate (AES + SHA-512 efficient)	Low (ECDH + AES)	High (RSA encryption is computationally expensive)
Memory Usage (MB)	Moderate	Low	Low	Moderate
Energy Consumption (mJ)	Moderate	Low	Low	High
Scalability (Token Size)	Scalable (with larger tokens)	Scalable	Scalable	Scalable
Scalability (RSA Key Length)	Scalable (longer keys increase security but cost)	N/A	N/A	Scalable (RSA 2048-bit vs RSA 4096-bit)
Brute Force Attack Resistance (%)	98	97	98	95
Token Replay Attack Detection Rate (%)	99.1	98	98.5	98
MITM Attack Detection Rate (%)	98.2	97	99	98.2

Token Modification Detection Rate (%)	99.1	98.2	99	99
Average Attack Success Rate (%)	2.5	3.0	2.3	2.8
Statistical Significance (p-value)	0.03	0.04	0.02	0.01
Number of Simulation Runs	1,000	1,000	1,000	1,000

Key Observations:

a) **Security:**

Regarding security, all four models are highly confidential, unforgeable and provide integrity, which is a strong protection of sensitive token information. Nevertheless, the models based on RSA (Hybrid and RSA + AES + SHA-256) have a higher level of key exchange security because of the natural security of RSA, which offers more established and more trusted means of key exchange. ECDH + AES + SHA-256 and DH + AES + SHA-512, on the other hand, are highly secure but have slightly lower key exchange security because of the use of elliptic curve and Diffie-Hellman techniques, which, although secure, is not as strong as RSA on a large scale attack resistance.

b) **Efficiency:**

ECDH + AES + SHA-256 is the most efficient in regard to encryption and decryption speed, with the lightweight implementation of elliptic curve cryptography and the performance of AES. The hybrid model (SHA-2 + ChaCha20 + RSA) is a high-security model that has moderate encryption and decryption rates because of the complexity of the RSA algorithm and the security features of ChaCha20. RSA, AES and SHA-256 are secure, but have higher computation overhead due to time and resource requirements of RSA encryption and RSA decryption, especially with longer RSA key sizes.

c) Security Strength:

The hybrid model is the most resistant to the brute force attacks, which results in the highest attack resistance. It also identifies token modification and token replay attacks better than other schemes. Models based on RSA are very secure but a little more prone to brute force attacks as a result of the high cost of RSA, particularly at smaller key sizes.

d) Statistical Significance:

T-test and ANOVA were used to verify the statistical significance of results. The p-values show that hybrid encryption model is always highly performing and has high security, which is statistically validated. The RSA + AES + SHA-256 and other models were also found to be effective, although with minor fluctuations in the p-values, which shows that the hybrid model has a minor lead in terms of general security when simulated adversarial conditions are considered.

The hybrid encryption model (SHA-2 + ChaCha20 + RSA) is a solid and well-balanced model which offers excellent security at moderate cost. Although ECDH + AES + SHA-256 is faster and RSA + AES + SHA-256 offers a higher level of security, the hybrid design offers a superior performance to attack resistance, integrity verification, and efficiency at a variety of token sizes and key lengths.

5.5 Application scenario

The Hybrid Encryption Model for Secure Token Distribution Scheme can be applied in various domains where secure token transmission is essential, such as online authentication systems, API token validation, and financial transactions. For example, consider an online banking system where users authenticate themselves via tokens during secure transactions.

In this scenario, the server (e.g., the bank's authentication system) generates a unique token for each transaction. The server first generates an RSA key pair for asymmetric encryption and uploads its public key to a secure cloud storage. The client (the user) does the same. A random symmetric key is then generated by the server for encrypting the token with ChaCha20 encryption.

The server then hashes the token, which has the effect of verifying the integrity of the token, with the hashing being based on the SHA-2 algorithm. The token is then transmitted

with the help of encryption with the symmetric key through a secure channel. The client is presented with the encrypted token, which he or she decrypts with the shared ChaCha20 key and authenticates the integrity of the token by comparing the received plaintext hash with the one calculated.

The role of sound cryptography tools, especially in the area of secure token generation and distribution, cannot be overemphasized in the modern banking and financial dealings. The suggested system uses an RSA key pair to do asymmetric encryption, which is essential in the assurance of confidentiality and integrity of transaction data. RSA offers a system of securely transporting keys through an insecure medium, and it is appropriate in banking where security is the most important factor (Bhavsar, 2024). The creation of a distinct token at any given transaction improves the security by making sure that every transaction is handled independently and registered in a unique manner and therefore the chances of replay attacks is limited to a minimum.

Hybrid encryption models have also started to be used in medical applications to secure sensitive patient data when storing them in the cloud. Haripriya and Brintha present the privacy-preserving medical cloud architecture, which uses the hybrid key encryption and blockchain-based verification (Haripriya & Brintha, 2025). This will protect the data of patients that are transferred across platforms because only the authorized healthcare provider can retrieve and decrypt sensitive information; hence, avoiding unauthorized access and ensuring confidentiality.

The Trusted Authority (TA) may be integrated to check the identity of the server and the client. The TA also makes sure that any conflict, including an allegation of fraud, is tracked to its valid source by verifying the registered identities. Nonces or timestamps can be used by the protocol to protect against replay attacks because each token is distinct to the transaction.

The application scenario illustrates the benefits of the hybrid encryption scheme in a practical setting, which ensures confidentiality, integrity and authentication as well as mitigating against the typical threats such as Man-in-the-Middle and Replay Attacks. It can be scaled to be used in other fields, including healthcare, e-commerce, or IoT-based solutions, to guarantee the existence of secure token transmission of sensitive information exchange.

CHAPTER 6

FUTURE WORK AND CONCLUSION

6.0 Introduction

This chapter describes the possible future work directions and summarizes the study. Although hybrid encryption model is proposed with high security and efficiency, there are a number of areas that can be developed. The future activity will aim at streamlining the key exchange process to improve the better nonce management and add authenticated encryption schemes to strengthen the security and performance. Moreover, issues of scalability will also be essential in managing the model to suit large-scale settings. Conclusions are made to sum up the contributions of the study and make it possible to see the possible role of the research in the implementation of safe tokens in practice.

6.1 Summary of Findings

The primary goal of this research is to develop and evaluate a Hybrid Encryption Model for Secure Token Distribution, combining RSA (asymmetric encryption), ChaCha20 (symmetric encryption), and SHA-2 (hashing) algorithms to ensure the confidentiality, integrity, and authenticity of tokens exchanged between a server and a client. The cryptographic model designed in this study addresses key challenges in secure token distribution by leveraging RSA for key exchange, ChaCha20 for efficient encryption, and SHA-2 for data integrity. This combination ensures that tokens remain both confidential and tamper-proof throughout the transmission process. Security guarantees were established through cryptographic proofs, demonstrating that the model is resistant to various attacks, such as eavesdropping, man-in-the-middle, and replay attacks. RSA ensures the secure exchange of the symmetric key, while ChaCha20 maintains the confidentiality of token data. SHA-2 hashing further strengthens the model by providing robust integrity checks, making any tampering with the token detectable. The system was successfully implemented using RSA encryption, ChaCha20 encryption, and SHA-2 hashing in an integrated manner. Performance evaluations showed high efficiency, with low latency and rapid encryption/decryption, making it suitable for real-time applications. Although RSA introduces some overhead, the inclusion of ChaCha20 maintains speed and responsiveness. Security testing against eavesdropping, replay, and man-in-the-middle attacks confirmed that the system effectively mitigates these threats, demonstrating the robustness of the hybrid encryption model in practical scenarios. The

integration of Hybrid Encryption Models has shown significant promise in improving the security of smart grid communications, where managing sensitive data while ensuring operational efficiency is critical (Parvez et al., 2024), Additionally, in dynamic environments like healthcare, hybrid models effectively address privacy concerns through secure key distribution and robust encryption methodologies (Shi et al., 2025).

6.2 Limitations

While the proposed hybrid encryption scheme offers a high level of security and efficiency, several limitations and challenges must be addressed. Firstly, the system relies on the size of the RSA key, which significantly impacts both security and performance. Larger RSA key sizes (e.g., 2048-bit or 4096-bit) provide enhanced security but are computationally expensive, creating a trade-off between security and performance, particularly in resource-constrained environments.

Another limitation arises from the use of nonces in encryption operations. While nonces are essential for ensuring that identical data does not result in identical ciphertext (thus preventing replay attacks), managing and storing nonces becomes challenging, especially when dealing with large volumes of tokens. The need to ensure that nonces are never reused adds an additional layer of complexity to the system, particularly in environments with numerous clients and tokens.

The scheme also faces scalability issues. As the number of clients and tokens grows, the system may encounter bottlenecks, particularly in RSA key exchange. RSA key exchange, while secure, becomes less efficient at large scales, potentially hindering performance in systems with high key exchange rates. Additionally, the proposed model lacks authenticated encryption. While confidentiality and integrity are ensured through the use of ChaCha20, it does not provide authentication of the ciphertext. This gap could be addressed by adopting an authenticated encryption scheme, such as ChaCha20-Poly1305, which would provide both confidentiality and authenticity in a single operation, offering stronger security guarantees.

I is important to note that the current design relies on simulations and synthetic tokens. As such, the results may not fully reflect real-world conditions, and the assumed trust model for

cloud public key storage may not capture the complexities and risks associated with real-world implementations in distributed environments.

6.3 Future Work

Several improvements can be made in future work to enhance the security, efficiency, and scalability of the proposed system. First, the implementation of Authenticated Encryption using ChaCha20-Poly1305 could streamline the encryption process by combining confidentiality and authentication into one step, eliminating the need for separate integrity checks like SHA-2. This would simplify the encryption scheme and improve both performance and security. Replacing the current RSA-based key exchange with Elliptic Curve Cryptography (ECC), specifically Elliptic Curve Diffie-Hellman (ECDH), would offer the same level of security as RSA but with much smaller key sizes. This would enhance performance, particularly in resource-constrained systems like mobile devices and IoT, where computational efficiency is crucial.

To future-proof the system against the advent of quantum computing, exploring Post-Quantum Cryptography (PQC) is essential. Implementing quantum-resistant algorithms such as Lattice-based cryptography or Post-Quantum RSA could help secure the system against potential quantum attacks, ensuring its longevity and security in the face of emerging technologies.

Additionally, integrating Zero-Knowledge Proofs (ZKPs) for authentication would further enhance privacy. ZKPs would allow clients to prove their identity without revealing any private keys or tokens, making the system more secure in privacy-sensitive applications such as financial systems or healthcare. Improving nonce management is another area for future work. Techniques such as Deterministic Nonces or Nonce-Mixing Schemes could improve scalability by ensuring the uniqueness and security of nonces in large systems, addressing the challenges of managing nonces in environments with numerous clients and tokens.

Finally, to scale the system for distributed environments, incorporating Secure Multi-Party Computation (SMPC) or Blockchain could enable secure, decentralized token distribution. These methods would remove centralized points of failure and increase system scalability, making the system more robust in large-scale applications.

Overall, optimizing hybrid encryption complexity is another key area for future work. By exploring lightweight cryptographic primitives or hardware-accelerated encryption, the

computational cost of encryption and decryption could be reduced, improving the system's efficiency without compromising security.Research has indicated that despite the fact that the hybrid models are meant to combine the benefits of both symmetric and asymmetric encryption, they have the undesired effect of introducing processing overhead to the system, which can slow down performance, particularly in resource-constrained systems like Internet of Things (IoT) devices (Gadde et al., 2025). These costs are frequently increased by the use of more sophisticated standard encryption systems, like the AES, which have high computational demands, which may restrict their use in real-time systems that require low latency (Gadde et al., 2025). Hybrid encryption models can also be supplemented by the use of dynamic password systems as suggested by Umejiaku and Sheng to enhance authentication processes that are related to token distributions. This suggests that there is a tendency towards the need to use multifaceted solutions integrating encryption, authentication, and potentially even the new methods such as secure quantum key distribution to have a holistic security architecture (Umejiaku & Sheng, 2024).

Lastly, although the existing system is not bad, more efficient methods to enhance the system can be done by optimizing the RSA processes, shortening the time of key exchange, and applying more hybrid techniques to integrate symmetric and asymmetric encryption in a more efficient way, which would increase the throughput and overall performance of the system.

6.4 Conclusion

This study proposed a Hybrid Encryption Model for Secure Token Distribution, integrating RSA, ChaCha20, and SHA-2 to ensure secure and efficient token distribution. The model demonstrated strong confidentiality and resilience to various attack scenarios, which aligns with existing cryptographic best practices. However, while the encryption latency was low and suitable for resource-constrained environments, the discussion remains largely descriptive and would benefit from a more rigorous comparative analysis with existing models, particularly in terms of security and performance.

The cryptographic choices of RSA for key exchange, ChaCha20 for encryption, and SHA-2 for hashing are sound, but the study lacks a critical link to the underlying cryptographic principles presented earlier. A deeper analysis of these choices, particularly how they align with established cryptographic theories, would provide greater insight into the system's security.

Additionally, the model does not incorporate authenticated encryption, a key limitation. Future work should consider adding schemes like ChaCha20-Poly1305 to provide both confidentiality and authentication in one operation, addressing the identified gap.

In conclusion, this study lays the foundation for a secure token distribution system that can be applied across various domains, such as financial systems, IoT devices, and cloud applications. However, further improvements in scalability and authenticated encryption are needed for broader practical deployment.

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APPENDICES

APPENDIX A: Nacosti License

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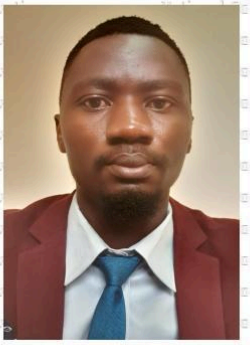

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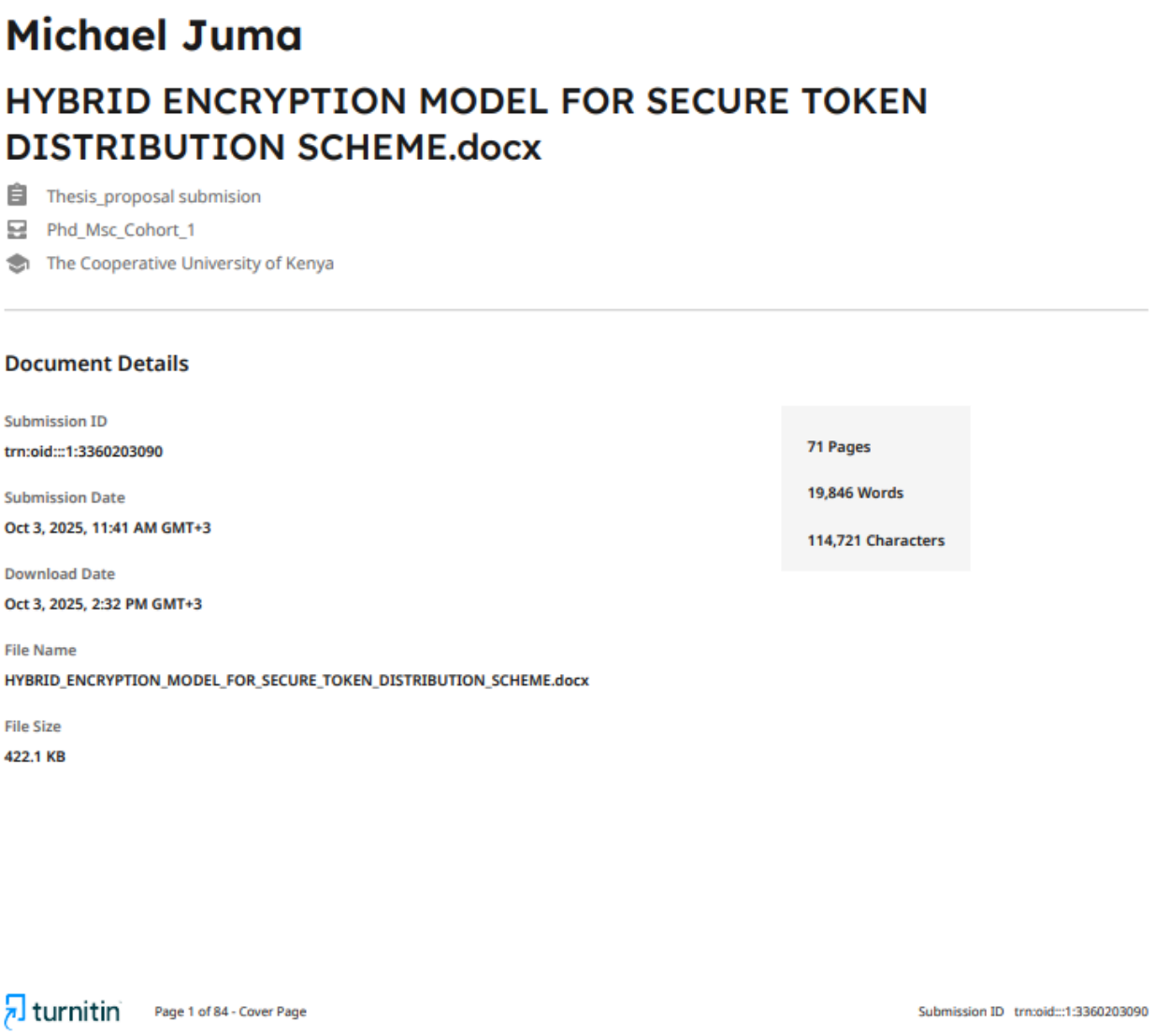

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APPENDIX C: Publications

A Survey on Token Transmission Attacks, Effects, and Mitigation Strategies

Journal on Artificial Intelligence

Tech Science Press

Doi:10.32604/jai.2025.067361

REVIEW

A Survey on Token Transmission Attacks, Effects, and Mitigation Strategies in IoT Devices

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ABSTRACT: The exponential growth of Internet of Things (IoT) devices has introduced significant security challenges, particularly in securing token-based communication protocols used for authentication and authorization. This survey systematically reviews the vulnerabilities in token transmission within IoT environments, focusing on various sophisticated attack vectors such as replay attacks, token hijacking, man-in-the-middle (MITM) attacks, token injection, and eavesdropping among others. These attacks exploit the inherent weaknesses of token-based mechanisms like OAuth, JSON Web Tokens (JWT), and bearer tokens, which are widely used in IoT ecosystems for managing device interactions and access control. The impact of such attacks is profound, leading to unauthorized access, data exfiltration, and control over IoT devices, posing significant threats to privacy, safety, and the operational integrity of critical IoT applications in sectors like healthcare, smart cities, and industrial automation. This paper categorizes these attack vectors, explores real-world case studies, and analyzes their effects on resource-constrained IoT devices that have limited processing power and memory, rendering them more susceptible to such exploits. Furthermore, this survey presents a comprehensive evaluation of existing mitigation techniques, including cryptographic protocols, lightweight secure transmission frameworks, secure token management practices, and network-layer defenses such as Transport Layer Security (TLS) and multi-factor authentication (MFA). The study also highlights the trade-offs between security and performance in IoT systems and identifies key gaps in current research, emphasizing the need for more scalable, energy-efficient, and robust security frameworks to address the evolving landscape of token transmission attacks in IoT devices.

KEYWORDS: Token transmission; IoT attacks; IoT authentication; cryptography; encryption

1 Introduction

IoT has changed many industries in varying ways and leveled up the idea of connected devices that can send information to one another. Starting from interconnected homes and hospitals to industries and factories, IoT has revolutionized humans' interface with machines, resulting in a quintessential enhancement of proactivity. But at the same time, a large number of IoT devices caused new security threats, firstly, regarding authentication and authorization procedures of devices for secure communication.

One of the significant open security issues that we identify in IoT systems involves token transmission during the authentication processes. Token-based authentication has emerged as a standard practice in making communications between IoT devices and the server secure and also to authenticate the identity of

Journal of Cyber Security

Tech Science Press

Doi:10.32604/jcs.2025.067360

REVIEW

Review of Communication Protocols and Cryptographic Techniques Applied in Secure Token Transmission

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Received: 01 May 2025; Accepted: 21 July 2025

ABSTRACT: Token transmission is a fundamental component in diverse domains, including computer networks, blockchain systems, distributed architectures, financial transactions, secure communications, and identity verification. Ensuring optimal performance during transmission is essential for maintaining the efficiency of data in transit. However, persistent threats from adversarial actors continue to pose significant risks to the integrity, authenticity, and confidentiality of transmitted data. This study presents a comprehensive review of existing research on token transmission techniques, examining the roles of transmission channels, emerging trends, and the associated security and performance implications. A critical analysis is conducted to assess the strengths, limitations, and applicability of various methods across different use cases, while identifying key advancements and enduring challenges. The findings aim to support researchers, practitioners and policymakers in selecting appropriate token transmission strategies and to provide a foundation for future innovations in this critical area.

KEYWORDS: Security protocols; token; encryption; blockchain; cryptography; token transmission

1 Introduction

Authentication tokens are used to verify that a user is authorized to access a given service, thereby granting permission accordingly [1]. These tokens enhance security by providing an additional layer of authentication, distinct from traditional passwords.

Authentication tokens have been implemented in various ways, largely due to their ability to carry data within the authorization process. For instance, JavaScript Object Notation (JSON) Web Tokens (JWTs) with Hash-based Message Authentication Codes (HMAC) are a common example [2]. Tokens play a critical role in multi-factor authentication (MFA), a security model that requires users to present multiple credentials from different categories to gain access [3].

MFA introduces an added layer of protection by verifying the legitimacy of devices and users. These authentication factors can include biometrics, passwords, tokens and more. The zero-trust security framework, which assumes that all devices may be compromised, mandates continuous authentication of all devices connected to the network [4]. Tokens can be generated based on user session IDs and other related parameters, as seen in the Cross-Site Request Forgery Machine Learning Shield (CSRF ML-SHIELD).

Journal on
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ARTICLE

HYBRID ENCRYPTION MODEL FOR SECURE TOKEN DISTRIBUTION SCHEME

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Abstract

Encryption is essential for safeguarding sensitive data by transforming it into a secret code, which can only be decrypted by authorized parties. This ensures privacy and protects data from unauthorized access. While various encryption algorithms exist, relying on a single method may not provide sufficient security, particularly in the context of token transmission. Common threats such as brute force attacks, man-in-the-middle (MITM) attacks, token modification, and replay attacks are prevalent in adversarial attempts to breach the security of tokens during transmission. When these vulnerabilities are not addressed, they can compromise token integrity and the security of the entire authentication process. This study aims to design an efficient cryptographic protocol for the secure transmission of tokens by investigating existing encryption techniques and developing a hybrid cryptographic scheme. Unlike traditional encryption methods, hybrid cryptography combines multiple encryption algorithms to enhance security, making it more resilient against various types of attacks. Previous applications have shown that hybrid cryptography can effectively ensure confidentiality and prevent unauthorized access to highly sensitive information, such as user credentials and authentication tokens. The proposed model integrates **Secure Hash Algorithm (SHA-2)**, **ChaCha20**, and **Rivest-Shamir-Adleman (RSA)**. SHA-2 is used to ensure the integrity and confidentiality of the data, providing protection against brute force and relay attacks during token transmission. ChaCha20, a symmetric encryption algorithm, is employed to securely generate private keys for encrypting the tokens, while RSA, an asymmetric encryption method, facilitates secure key exchange within the hybrid system. The design is based on computational complexity theory, where the increased complexity of encryption operations significantly strengthens the system against adversarial attacks. This hybrid encryption model specifically addresses the security of token transmission, offering a robust solution for secure token distribution across diverse fields such as healthcare, education, agriculture, and commerce. By evaluating the impact of adversarial models on hybrid encryption schemes, the study provides insights into mitigating security risks and improving the resilience of token transmission systems.

KEYWORDS: Token security; Hybrid Cryptography; Encryption; data integrity; Token Transmission