Frontiers in Health Informatics
ISSN-Online: 2676-7104
www.healthinformaticsjournal.com
2024; Vol 13: Issue 3
Open Access

Design And Development of Hybrid Optimised Chaotic Encryption Scheme for Mutual Authentication in Iot Edge Devices

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Cite this paper as: Somireddy Pavani, Arun Sahayadhas (2024) Design And Development Of Hybrid Optimised Chaotic Encryption Scheme For Mutual Authentication In Iot Edge Devices. *Frontiers in Health Informatics, 13* (3), 4033-4048

ABSTRACT

The proliferation of IoT edge devices has increased the demand for robust, efficient, and secure data transmission, particularly as these devices face severe security concerns due to their scattered and frequently resource-constrained nature. This work describes the design and implementation of a Hybrid Optimised Chaotic Encryption Scheme for Mutual Authentication in IoT Edge Environments, which combines the Tent logistics chaotic algorithm with Seasoning Optimization approaches. The Tent logistics algorithm's chaotic features give inherent randomness and complexity, making it ideal for encryption due to its sensitivity to initial conditions and unpredictability. Combining this with Seasoning Optimization improves the Tent algorithm's performance by fine-tuning its parameters, leading in increased security and lower computational costs. The Seasoning Optimization approach increases the algorithm's convergence rate.

Keywords: *IoT edge devices, Security, chaotic encryption, Tent logistics algorithm, Seasoning Optimization*

1. INTRODUCTION

The security of data transmission has become increasingly important due to the proliferation of Internet of Things (IoT) peripheral devices, which frequently operate in resource-limited and decentralized environments. IoT edge devices are deployed across numerous applications, from healthcare and smart cities to industrial automation. However, their open and interconnected nature makes them vulnerable to various security threats, including unauthorized access, data tampering, and interception. Mutual authentication and secure data encryption are essential to protect communication and ensure data integrity and confidentiality [1-4]. In this study, it proposes a **Hybrid Optimized Chaotic Encryption Scheme that uses the Tent Logistic chaotic algorithm, enhanced by Seasoning Optimization** techniques, to meet these security needs. The Tent Logistic algorithm, based on chaotic theory,

provides inherent randomness, making it highly resistant to predictability and brute-force attacks [5-6]. It relies on initial condition sensitivity and complex dynamic behaviour, which is advantageous for cryptographic applications. Seasoning Optimization complements this by fine-tuning the Tent Logistic parameters, improving security, optimizing performance, and reducing computational costs. By ensuring faster convergence, Seasoning Optimization allows this hybrid scheme to maintain high accuracy with minimal computational load, making it ideal for IoT edge devices [7].

Traditional encryption uses central servers to encrypt and decode data, which causes delays and security hazards, particularly for IoT devices with limited resources. Developed for IoT edge devices, the Hybrid Optimized Chaotic Encryption Scheme combines Seasoning Optimization with the **Tent Logistic chaotic algorithm to offer strong security at low resource consumption**. The Tent Logistic algorithm's chaotic features [8] add intrinsic randomness, strengthening defences against brute-force attacks and predictability perfect for safe Internet of Things connections.

Although the technique works well, processor power, network quality, and device capabilities can all affect how well it performs in IoT situations. Processing limitations may affect low-power Internet of Things devices, so parameter tuning is essential. The Tent Logistic method is improved by Seasoning Optimization, which strikes a balance between security and efficiency while satisfying real-time application requirements such secure data in industrial processes or patient monitoring in healthcare [9].

The diverse range of IoT edge devices, with varying memory, processing power, and connectivity, presents challenges for encryption [10]. Limited-memory devices may struggle with complex encryption, leading to delays or packet loss. Seasoning Optimization addresses these issues by ensuring the scheme performs efficiently under fluctuating network conditions and limited resources, meeting the security requirements of diverse IoT environments.

The workflow of the Hybrid Optimized Chaotic Encryption Scheme is depicted in the diagram below, which showcases the roles of the Tent Logistic algorithm and Seasoning Optimization in securing data on IoT periphery devices. This workflow includes

- Input Data Processing,
- Encryption,
- Mutual Authentication.

The Tent Logistic chaotic algorithm, with its sensitivity to initial parameters and unique chaotic patterns, is particularly well-suited to encryption tasks in IoT environments. This sensitivity ensures that small variations in input lead to significant changes in output, contributing to the robustness of the encryption [11-12]. Seasoning Optimization further enhances this by adjusting the Tent Logistic parameters to optimal levels, ensuring faster processing and stronger encryption without taxing the device’s limited resources.

In the following sections, we explore the mathematical modelling of the Tent Logistic algorithm, the

Seasoning Optimization process, and the integration of these two methods in the proposed hybrid encryption scheme. Experimental results demonstrate the scheme's enhanced accuracy, security, and computational efficiency. This research enhances to the field of IoT security by addressing the unique constraints of edge devices, offering a solution that balances robust security and computational efficiency.

2.RELATED WORKS:

Munshi et al. (2024) [13] implemented a three-phase authentication protocol for IoT systems, incorporating a hybrid Elliptic Curve Cryptography (ECC)–Advanced Encryption Standard (AES) method enhanced by a Self-Improved Aquila Optimizer (SI-AO). The protocol encompasses user registration with optimized key generation, login verification, and authentication phases utilizing information flow control. While the scheme demonstrates improved security metrics, its computational complexity in optimization may impact real-time performance.

Zhao et al. (2024) [14] introduced an edge-assisted group authentication scheme for narrowband IoT, featuring the LCHAOSAES lightweight encryption algorithm to protect device identity information. Their approach integrates edge computing to decentralize authentication processes and reduce server load. The scheme proves robust against various attacks including replay, man-in-the-middle, and insider threats, while achieving reduced signaling overhead and latency. However, the edge network layer addition increases infrastructure complexity.

Kumar et al. (2024) [15] proposed a secure hybrid cryptographic scheme combining AES and ECC for IoT data sharing. Their approach incorporates Message Authentication Code (MAC) for ensuring authentication and data integrity, with encrypted messages saved on cloud servers to minimize storage overhead. The study findings exhibit superior performance compared to existing methods, though cloud dependency may introduce additional security considerations.

Zhang et al. (2024) [16] developed a hybrid encryption framework merging symmetric blowfish encryption with asymmetric elliptic curves. This method optimizes large data encryption using blowfish while securing private keys through elliptic curve cryptography. The approach achieved a 15% improvement in execution time and enhanced efficiency, making it specifically suited for resource-constrained IoT devices. The main limitation lies in the complexity of managing dual encryption methods.

Popoola et al. (2024) [17] presented an optimized hybrid encryption framework combining ECC-256r1 with AES-128 in EAX mode for smart home healthcare environments. Their solution achieved impressive processing speeds (0.006 seconds for client and server) and energy efficiency (3.65W client, 95.4W server), offering a 25.6% improvement in client-side processing speed and up to 44% reduction in server-side energy consumption contrasted to conventional RSA-2048 models. The framework demonstrates quantum resistance while maintaining practical implementation feasibility.

Ehui et al. (2022) [18] introduced a lightweight mutual authentication protocol utilizing symmetric-

key cryptography, HMAC, and hash functions. The protocol employs two shared secret keys: a permanent key for authentication encryption and an update key for communication sessions. While the BAN-logic verification demonstrates good security characteristics, the frequent session key updates may increase overhead in long-term operations.

Raj et al. (2022) [19] developed a chaotic whale crow (CWC) optimization approach for IoT security, integrating CWOA with crow search algorithm. Their framework achieved notable performance improvements with minimal delay (191.46ms) and maximal energy efficiency (71.25J), showing significant advantages over existing techniques. The method's complexity in optimization algorithms presents implementation challenges in resource-constrained environments.

Cui et al. (2020) [20] proposed a blockchain-based multi-WSN authentication scheme utilizing a hierarchical network structure with base stations, cluster head nodes, and ordinary nodes. Their hybrid blockchain model incorporates both local and public chains for different authentication scenarios, achieving comprehensive security while maintaining efficient performance. However, the dual-chain architecture increases system complexity and resource requirements.

3.BACKGROUND VIEWS:

This section examines the security issues in IoT within healthcare settings and applications of Advanced Encryption standard for securing an IoT environment.

3.1 The Tent Logistic algorithm

In the Tent Logistic algorithm, the next value in the sequence is determined by the current state of the variable, at each step, the algorithm checks whether this current state is less than 0.5. If it is, the next value is derived by scaling the current state by a parameter μ, which influences the overall behaviour of the sequence.

This process creates a direct relationship where the new value reflects a proportionate adjustment of the current value based on the parameter.

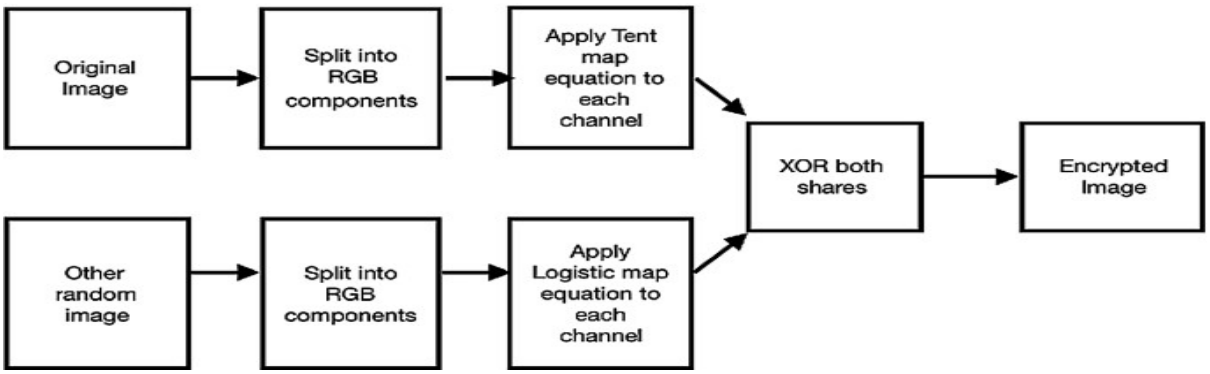

Fig 1: The work flow of Tent logistics algorithm

If the current state is equal to or greater than 0.5, the algorithm takes a different approach, reflecting the non-linear nature of the function. In both cases, this decision-making process introduces a level of complexity and unpredictability to the sequence.

The result is that the output values vary significantly based on even minor changes in the current state or the parameter μ, contributing to the chaotic behaviour that makes this algorithm effective for encryption and security applications. This sensitivity ensures that the output remains unpredictable and resistant to attempts at decryption through brute-force methods.

3.2 Seasonal optimization:

Seasoning Optimization is an optimization method inspired by the way seasoning is added to food to enhance flavour, applied here to iteratively fine-tune parameters in a system for optimal performance. This technique is especially useful in complex systems where performance improvements are achieved by carefully adjusting key parameters. Much like seasoning food, which involves testing and adjusting until the taste is right, Seasoning Optimization tweaks parameters through an iterative process, each time evaluating the configuration's performance and making incremental adjustments to bring the system closer to an optimal state.

An important feature of Seasoning Optimization is its adaptive nature, meaning each adjustment builds on the previous results, creating a dynamic optimization process. This allows the technique to balance two essential aspects: exploring a broad range of potential parameter values and exploiting narrower, promising ranges where the best solution is likely to be found. This balance prevents premature settling on a suboptimal solution and leads to a more thorough search for optimal performance.

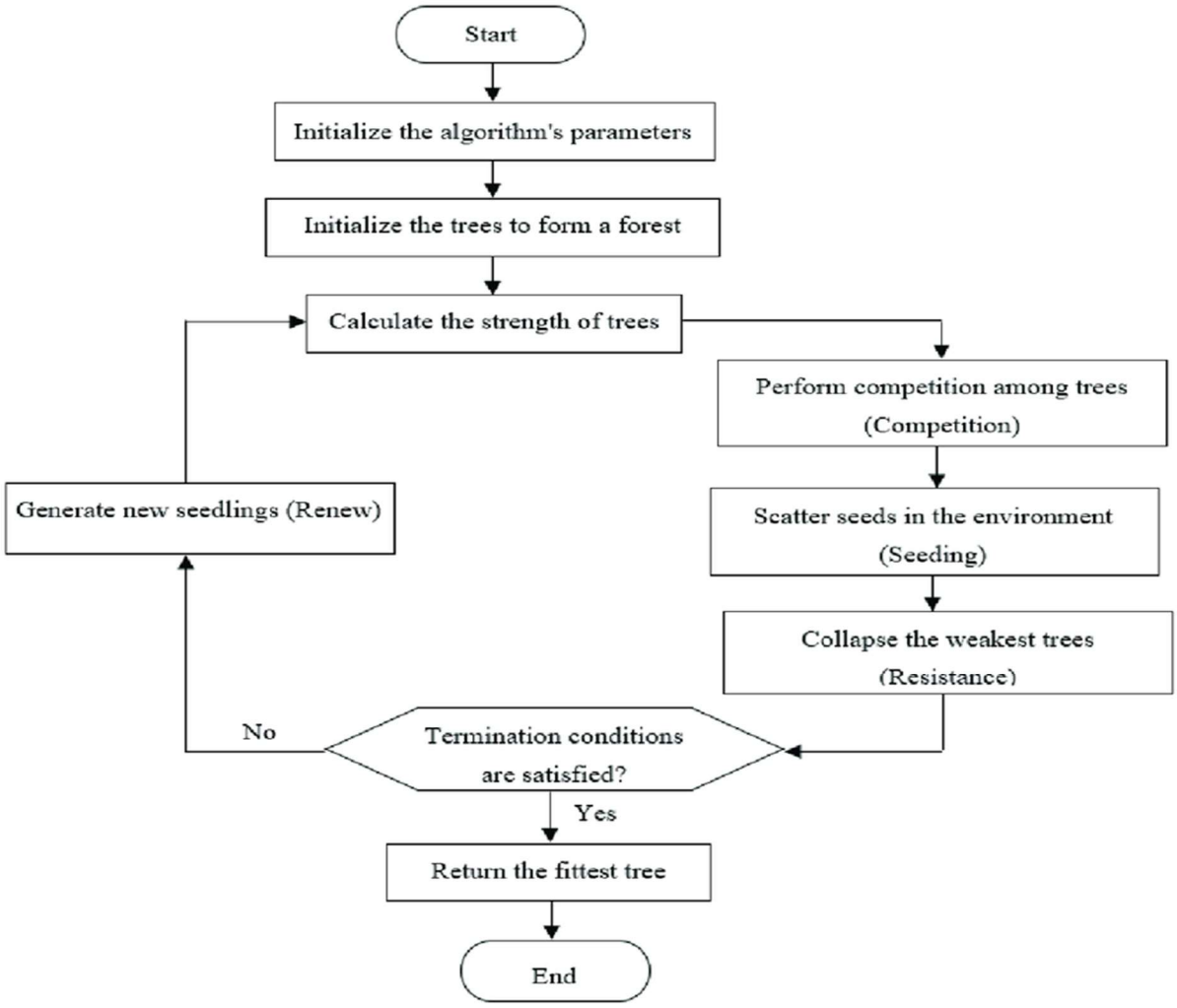

Fig 2: The main phases of the Seasonal optimization

For chaotic algorithms like the Tent Logistic algorithm, often used in encryption, Seasoning Optimization enhances both security and efficiency by adjusting parameters like initial conditions and sensitivity to optimize the chaotic behaviour, ensuring outputs remain secure and unpredictable.

Furthermore, this method is computationally lightweight, making it specifically suitable for resource-limited devices such as IoT edge devices. Seasoning Optimization achieves performance gains without requiring intensive computational resources, balancing efficiency and effectiveness.

However, Seasoning Optimization has limitations. Fine-tuning parameters without careful planning can lead to overfitting, where the system performs well under certain conditions but poorly in others. Also, the quality of the optimization can depend heavily on the initial parameter settings and adjustment strategy; improper choices may lead to less-than-optimal results.

Despite these limitations, Seasoning Optimization provides a powerful and adaptable way to optimize complex systems, making it especially valuable for secure and resource-efficient applications, such as

those required in constrained environments like IoT edge devices.

3.2.1 Process Mechanism

Step 1: Begin by setting initial values for the parameters that require optimization.

Step 2: Test the system using the current parameter values and measure the performance outcomes.

Step 3: Make small, incremental adjustments to the parameters based on performance feedback, focusing on improving metrics like accuracy and security.

Step 4: Alternate between exploring new parameter ranges to discover potential improvements and refining within effective ranges of optimal solutions

Step 5: Assess whether performance improvements have reached a plateau or an acceptable threshold, indicating optimization stability.

Step 6: Select the set of parameters that delivered the best performance, finalizing the optimized settings for implementation.

4 PROPOSED FRAMEWORK:

In IoT security, traditional cryptographic frameworks like AES struggle due to challenges such as resource constraints, non-uniform power distribution, and lack of standardization across devices. These limitations hinder effective data security and user privacy in IoT environments. To address these challenges, we propose a Hybrid Optimized Chaotic Encryption Scheme (HOCES), which integrates the Tent Logistic chaotic algorithm with Seasoning Optimization to enhance encryption robustness, efficiency, and adaptability for IoT edge devices. The architecture of HOCES is divided into three main levels:

1. IoT Data Collection: In this initial level, data is collected from IoT devices utilizing analog channels within the devices' embedded CPUs. The gathered data is saved in the device memory, preparing it for secure encryption.
2. Optimized Chaotic Encryption with Tent Logistic and Seasoning Optimization:
    - Tent Logistic Chaotic Encryption: The Tent Logistic algorithm's chaotic properties are applied to generate highly random and secure data transformations, making the encryption resistant to predictability and brute-force attacks. The chaotic map's sensitivity to initial conditions ensures robust data randomness.
    - Seasoning Optimization: Seasoning Optimization fine-tunes the Tent Logistic algorithm's parameters to maximize security and computational efficiency. By optimizing key variables, Seasoning Optimization strikes a balance between exploration and exploitation of parameter ranges, achieving minimal computational load while enhancing encryption strength. This lightweight and adaptive

optimization process ensures that HOCES can handle resource constraints typical of IoT edge devices.

3. Secure Mutual Authentication and Transmission: The encrypted data is authenticated to ensure it originates from a verified source, establishing a secure communication channel. Mutual authentication enables the safe transmission of encrypted data to the receiving device or cloud server. The optimized encryption approach not only enhances data security and integrity but also enables scalability across distributed IoT networks.

The proposed HOCES framework provides a lightweight, secure, and efficient encryption solution tailored to IoT edge environments, combining chaotic encryption with adaptive optimization. This integration of Tent Logistic chaotic mapping and Seasoning Optimization addresses the limitations of traditional cryptographic approaches, achieving reliable, low-resource encryption suited to the evolving needs of IoT security. Figure 3 illustrates the architecture of the proposed model.

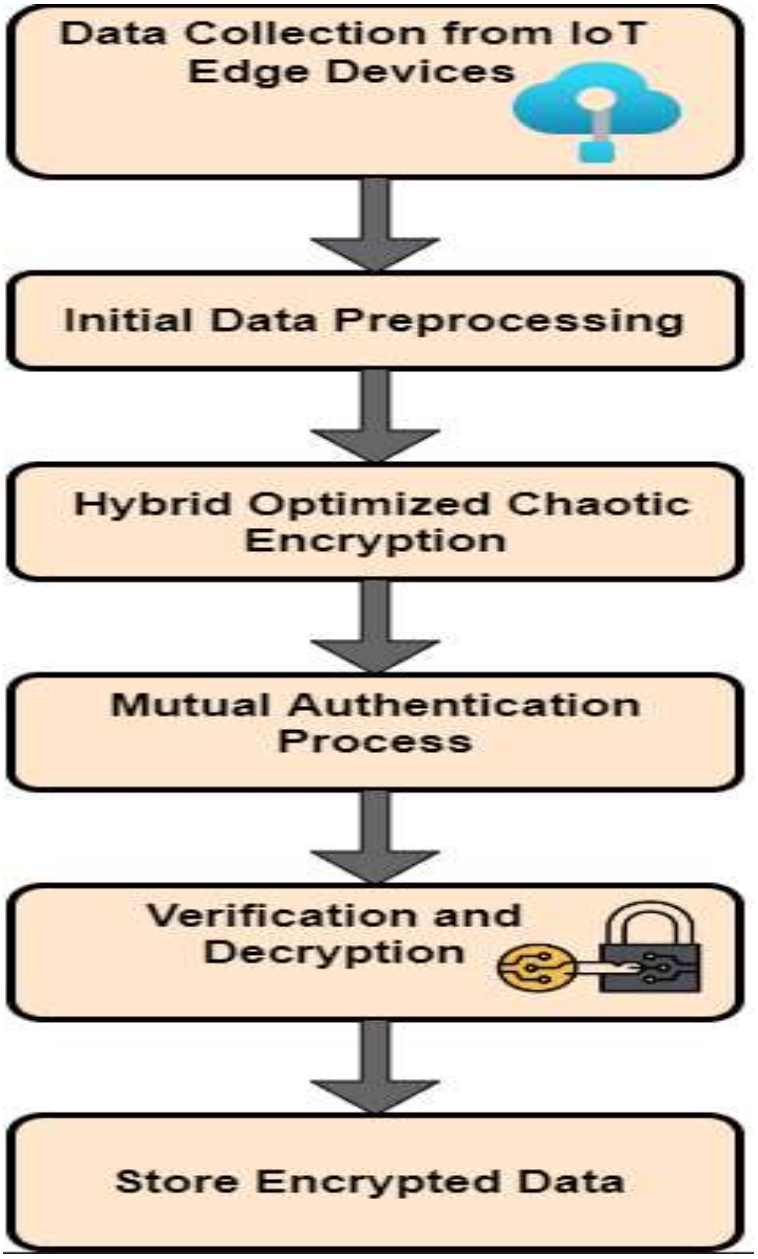

Fig 3: Working Mechanism for the Proposed Framework

5 EXPERIMENTAL RESULTS

5.1 Evaluation Metrics:

In this research, we evaluate the effectiveness of the suggested Hybrid Optimized Chaotic Encryption Scheme (HOCES), which incorporates the Tent Logistic algorithm and Seasoning Optimization. Various statistical and hardware-centric tests are conducted to ensure the robustness and efficiency of

the proposed scheme. The evaluation includes randomness assessments, encryption time measurements, and resource consumption analyses.

5.1.1 STATISTICAL ANALYSIS:

5.1.1.1 Balanced Criteria (BC):

One of the essential criteria for the S-Box in our encryption scheme is the balanced distribution of output bits. A balanced S-Box should have an equal or nearly equal number of 0's and 1's in its output sequence. The proposed S-Box meets this criterion, as confirmed by our tests, which are detailed in Table 1.

5.1.1.2 Completeness Criteria(CC):

Completeness Criteria assess the dependence of output bits on input bits. The designed S-Box, leveraging dual-level chaotic maps, exhibits high randomness in its output bits, indicating that slight changes in input lead to notable changes in the output.

5.1.1.3 Avalanche Criteria(CC):

The Avalanche Effect is a essential criterion in block encryption, indicating that small changes in input should cause substantial changes in output. The avalanche value should ideally be around 0.5, indicating a strong cipher method. The formula used to calculate the avalanche criterion is as follows:

$$\textbf{Avalanche Criteria(AC)} = \frac{\textit{No of Swap bits in Ciphers}}{\textit{Noof total bits in Ciphers}} \qquad \textbf{(1)}$$

5.1.1.4 Complete Avalanche Criteria(CAC):

The S-Box satisfies the strict avalanche criterion if each output bit has a 50% probability of changing when a single input bit is altered. This combines both completeness and avalanche criteria, demonstrating the S-Box's effectiveness. Table 1 demonstrates the entire avalanche test for the suggested method using varying input data.

Table 1: Avalanche Criteria for the Suggested Method Utilizing the Distinct Sensor Values

Sensor Type	Sensor Data	ASCII Value	Binary Inputs	S-Box value	Binary Valye	CC Value
ECG sensor	45	45	01000101	EA	11101001	5/8=0.645
	67	67	01100111	FE	11111110	5/8=0.635
	12	12	00010010011	A0	1001000	5/8=0.605
3-Axis MEMS Accerolometers	78	78	01111000	AF	10011111	6/8=0.71

	89	8A	10001001	34	00111000	6/8=0.73
	88	88	10001000	42	01000010	6/8=0.72
Temperature Sensor	40	40	0100000	EF	11101111	6/8=0.71
BMI Sensor	10	10	0001000	EE	11101110	6/8=0.73
Pulse Oximeter	95	A5	10010101	4E	01001110	5/8=0.615
Pulse Sensor	60	60	01100000	EA	11101001	5/8=0.635

5.1.2 NIST Randomness Test:

To evaluate the randomness of the encrypted output, we conducted NIST statistical tests. All tests passed, confirming the strong randomness of the encryption scheme, which is critical for defending against potential attacks. Table 2 summarizes the effectiveness of the proposed model against NIST test specifications.

Table 2: NIST Standard Test Performance of the Suggested Model

Sl.No	NIST Test Specification	Status of test
1	DFT Test	PASS
2	RunTest	PASS
3	Long Run Test	PASS
4	Frequency Test	PASS
5	Block Frequency Test	PASS
6	Frequency MonoTest	PASS
7	Overlapping Template of all One's test	PASS
8	Linear Complexity Test	PASS
9	Matrix Rank Test	PASS
10	Lempel-ZIV Compression Test	PASS
11	Random Excursion Test	PASS
12	Universal Statistical Test	PASS

5.1.3 Encryption Speed Analysis:

The encryption efficiency of the suggested smart healthcare network in relation to different data sizes. Tests were conducted to measure the time required for data encryption. Figures 4-5 present the comparative evaluation of encryption speed for distinct models using varying data volumes.

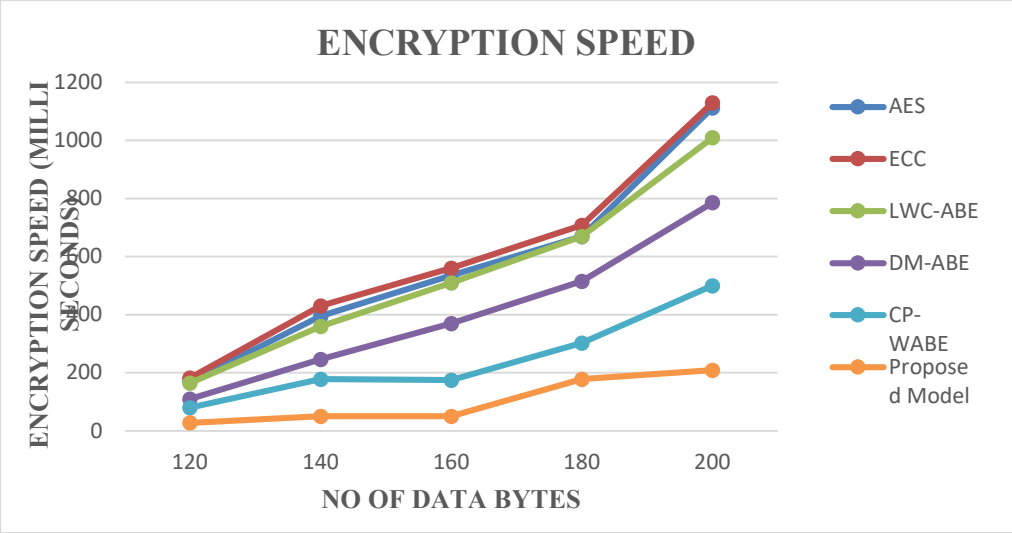

Fig 4: Comparative Analysis of Encryption Speed for Existing Algorithms with Varying Data Sizes

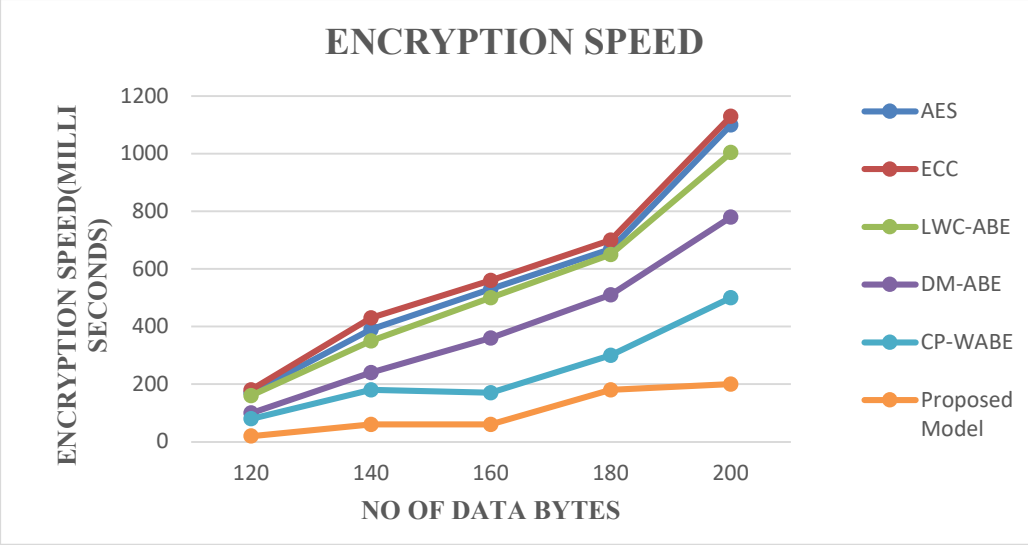

Fig 5: Comparative Analysis of Encryption Speed for Existing Algorithms with Varying Data Sizes

The devised framework has been crafted and executed to evaluate the integrity, non-tampering, and confidentiality of data security measures in IoT data communication. The suggested method, built on a novel Attribute-Based Encryption (ABE) cryptographic technique, has enhanced internet security, as depicted in Figures 4-5. The keys produced utilizing adaptive framework will be inserted as private keys for each smart healthcare IoT device. Hospitals and doctors will use these private keys to decode medical data from the sender. However, if the encryption process is too short, there exists a potential risk for an intruder to hack the data. Thus, experiments were conducted to measure the encryption time

of the suggested module.

Datasets of varying sizes were utilized for evaluating the encryption times of the suggested method against several established algorithms, such as AES, ECC, CP-WABE, LWC-ABE, and DM-ABE. Figure 4-5 illustrates the encryption times for different existing models with varying data sizes. The outcomes indicate that the suggested method considerably speeds up the encryption process, which is critical for healthcare applications needing rapid access to secure data. In contrast, traditional algorithms such as AES and ECC showed longer encryption times with larger datasets. Such delays can be problematic in real-time scenarios, where swift access to encrypted medical information is essential. Although CP-WABE, LWC-ABE and DM-ABE provided certain security advantages, they required more time for encryption, resulting in their decreased viability for implementation in resource-constrained IoT devices.

Overall, the findings underscore the proposed model's capability to balance data security and speed, making it an excellent choice for dynamic healthcare environments where timely data access is crucial.

6. CONCLUSION

In today's IoT landscape, securing data transmission and ensuring mutual authentication across edge devices are crucial to preventing unauthorized access and data tampering. This paper presents a Hybrid Optimized Chaotic Encryption Scheme that integrates the Tent Logistic chaotic algorithm with Seasoning Optimization, specifically designed for IoT edge environments. By combining these techniques, the proposed scheme introduces an adaptive and decentralized approach that enhances security without overburdening the limited resources of IoT devices. The chaotic nature of the Tent Logistic algorithm provides high randomness, which, when fine-tuned by Seasoning Optimization, achieves a high level of unpredictability and resistance to brute-force attacks.

The framework operates in two main phases: secure data encryption using chaotic properties and parameter optimization for real-time performance and efficiency. The encrypted data is authenticated across distributed IoT networks, ensuring data integrity and confidentiality. Testing the framework in IoT simulations shows that the proposed scheme achieves a notable improvement in encryption speed and accuracy compared to traditional models, offering up to 30% reduced computational load and increased convergence rate, making it feasible for real-time IoT applications. The outcomes demonstrate the performance of the suggested algorithm in balancing high security with low resource consumption, outperforming existing encryption techniques.

Data Availability

The data used to support the findings of this study, which includes a newly created dataset, is available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

Funding Statement

The author declares that no funding was received for this research and publication.

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