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Deimos Cipher: A High-Entropy, Secure Encryption Algorithm with Strong Diffusion and Key Sensitivity

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Abstract

Deimos Cipher is a symmetric encryption algorithm designed to achieve high entropy and strong diffusion while maintaining efficiency. It employs advanced cryptographic transformations to ensure robust security against modern cryptanalysis techniques. Entropy tests demonstrate its ability to generate highly randomized ciphertext, surpassing industry standards. Avalanche effect analysis confirms optimal diffusion, achieving an average bit change of 50.18% in large datasets. Key sensitivity tests reveal a 50.54% ciphertext difference for minimal key variations, ensuring strong resistance to differential cryptanalysis. With fast encryption and decryption speeds, Deimos Cipher offers a balanced approach between security and performance, making it suitable for secure communication and data protection. This paper presents the algorithm's design, security analysis, and benchmarking against established cryptographic standards.

Keywords: Deimos Cipher, Symmetric Encryption, Cryptography, Entropy, Avalanche Effect, Key Sensitivity, Secure Communication

1. Introduction

With the increasing reliance on digital communication and cloud-based data storage, the need for robust encryption techniques has become paramount. The rapid growth of cyber threats, including data breaches, cryptanalysis techniques, and side-channel attacks, highlights the necessity of developing cryptographic algorithms that offer both high security and efficiency. Traditional encryption methods, such as the Advanced Encryption Standard (AES) and ChaCha20, have been widely adopted due to their proven security. However, evolving cryptanalytic techniques and emerging threats, including quantum computing, necessitate the continuous development of more resilient cryptographic systems.

AES, while highly secure, has been shown to be vulnerable to side-channel attacks, including timing and power analysis attacks. ChaCha20, a modern alternative, provides better resistance to such attacks and improved efficiency on low-power devices. However, entropy analysis has demonstrated that short plaintexts encrypted with these algorithms often exhibit nonoptimal randomness, which could lead to potential statistical weaknesses. Moreover, ensuring optimal diffusion—where a small change in input results in a large, unpredictable change in output - is a critical challenge in symmetric encryption.

To address these challenges, 1 introduce Deimos Cipher, a novel hybrid symmetric encryption algorithm that aims to enhance entropy, improve key sensitivity, and maximize diffusion. Deimos Cipher integrates XChaCha20 for encryption, BLAKE2b for key expansion, and HMAC-SHA-256 for authentication, creating a multi-layered cryptographic approach. By leveraging a high-entropy key derivation function (HKDF) and a robust authentication mechanism, Deimos Cipher ensures that ciphertext exhibits strong randomness, resistance to differential cryptanalysis, and minimal information leakage.

The primary contributions of this paper are as follows:

- Design and development of Deimos Cipher, a high-entropy, key-sensitive encryption algorithm.
- Entropy and diffusion analysis demonstrating that Deimos Cipher achieves significantly higher randomness and key sensitivity compared to AES and ChaCha20.
- Comprehensive performance evaluation, comparing encryp-

tion and decryption speeds, ciphertext length consistency, and security robustness with established ciphers.
- Discussion on real-world applications, including secure messaging, cloud storage encryption, and data protection in high-security environments.

The remainder of this paper is structured as follows: Section 2 reviews existing encryption standards and their limitations. Section 3 details the design principles and encryption methodology of Deimos Cipher. Section 4 presents a security evaluation, including entropy tests, key sensitivity, and the avalanche effect. Section 5 compares performance metrics with existing encryption algorithms. Section 6 discusses potential real-world applications of Deimos Cipher. Finally, Section 7 summarizes the findings and suggests future research directions.

2. Related Work

2.1. Existing Symmetric Encryption Algorithms

Symmetric encryption algorithms play a crucial role in securing digital communications and protecting sensitive information. The most widely used symmetric ciphers include AES, ChaCha20, and other stream and block ciphers.

1. *Advanced Encryption Standard (AES)*: AES, introduced by the National Institute of Standards and Technology (NIST), operates on 128-bit blocks with key sizes of 128, 192, or 256 bits. While AES is widely trusted, it is susceptible to side-channel attacks, such as power analysis and cache timing attacks. Additionally, AES requires complex key scheduling, which may introduce implementation vulnerabilities if not handled securely.
2. *ChaCha*20: ChaCha20, designed by Bernstein, is a stream cipher that offers improved security over traditional ciphers like RC4. Unlike AES, it is resistant to timing attacks and performs efficiently on low-power devices. However, entropy analysis indicates that short plaintexts encrypted with ChaCha20 may exhibit lower randomness than expected, which could theoretically introduce statistical weaknesses.
3. *XChaCha*20: A variant of ChaCha20, XChaCha20 extends the nonce length to 192 bits, enhancing nonce-misuse resistance. It is widely used in modern cryptographic protocols due to its efficiency and strong security guarantees. However, like its predecessor, it does not provide built-in authentication, requiring additional mechanisms such as HMAC (Hashed Message Authentication Code) to ensure integrity.

2.2. Cryptographic Techniques for Enhanced Security

Several cryptographic techniques have been developed to strengthen symmetric encryption algorithms:

- Key Derivation Functions (KDFs): Secure key expansion techniques, such as PBKDF2, Scrypt, Argon2, and HKDF, play a crucial role in strengthening password based encryption. The use of HKDF with BLAKE2b in Deimos Cipher ensures that the derived keys exhibit high entropy and resilience against brute-force attacks.
- Hash-Based Authentication: Ensuring the integrity of encrypted data requires cryptographic authentication techniques like HMAC. Deimos Cipher integrates HMAC-SHA-256 to verify the authenticity of ciphertext, mitigating the risk of data tampering.
- Avalanche Effect and Diffusion Principles: The avalanche effect is a fundamental property of secure cryptographic algorithms, where a minor change in plaintext or key results in significant alterations in the ciphertext. Existing ciphers, including AES and ChaCha20, exhibit strong avalanche properties in large datasets. However, for smaller inputs, diffusion is often weaker, leading to potential vulnerabilities in constrained environments. Deimos Cipher addresses this issue by incorporating highly randomized transformations, ensuring that ciphertext remains unpredictable regardless of input size.

2.3. Limitations of Existing Approaches

Despite their robustness, traditional encryption algorithms exhibit several limitations:

- Predictable Entropy in Small Ciphertexts: AES and ChaCha20 may exhibit lower entropy when encrypting small plaintexts, making statistical attacks feasible in constrained environments.
- Fixed-Block Structure in AES: AES's block-based structure can introduce pattern recognition vulnerabilities if used in modes like ECB (Electronic Codebook). Although CBC, GCM, and other AES variants mitigate this, they require careful nonce handling.
- Key Sensitivity and Cryptanalysis Resistance: A highly secure cipher must exhibit strong key sensitivity, ensuring that a single-bit modification in the key results in an entirely different ciphertext. While AES and ChaCha20 provide reasonable key sensitivity, our analysis demonstrates that Deimos Cipher achieves a higher degree of key sensitivity through its multi-key transformation process.

2.4. Need for Deimos Cipher

To overcome the above challenges, Deimos Cipher is designed with the following improvements:

- Enhanced entropy generation, ensuring ciphertext exhibits near-uniform randomness across varying plaintext sizes.
- Stronger diffusion properties, optimizing the avalanche effect to prevent cryptanalysis.
- Robust authentication mechanisms, integrating HMAC-SHA-256 for message integrity.
- Efficient performance trade-offs, balancing security and computational overhead.

The following sections detail the methodology, security analysis, and performance evaluation of Deimos Cipher, demonstrating its superiority over existing cryptographic standards.

3. Methodology

3.1. Overview of Deimos Cipher

Deimos Cipher is a symmetric-key encryption algorithm designed to maximize security while maintaining computational efficiency. It incorporates a multi-layered transformation process involving XChaCha20 for stream encryption, HKDF with BLAKE2b for

key expansion, and HMAC-SHA256 for integrity verification. The design ensures strong randomness, a high Avalanche Effect, and robust key sensitivity, making it resistant to cryptanalytic attacks.

The encryption process begins with generating a random salt and deriving three cryptographic keys using HKDF:

- K_1: Used for stream encryption with XChaCha20.
- K_2: Reserved for future enhancements, such as additional security layers.
- K_3: Used for HMAC-SHA256 to ensure message integrity.

The decryption process first validates the HMAC before performing decryption, preventing unauthorized modifications.

3.2. Key Expansion using HKDF-BLAKE2b

To derive secure encryption keys from a user-supplied password, Deimos Cipher employs the HMAC-based Key Derivation Function (HKDF) with the BLAKE2b-512 cryptographic hash function. This ensures that even weak passwords are transformed into highly secure cryptographic keys. The key derivation process is performed as follows:

1. Generate a 32-byte random salt to enhance security.
2. Compute the pseudo-random key (PRK) using HKDF with BLAKE2b.
3. Expand the PRK into three 256-bit keys: K_1, K_2, and K_3, each derived with unique context information.

3.3. Encryption Process

The encryption process of Deimos Cipher follows these steps:

1. Salt Generation: A 32-byte salt is randomly generated.
2. Key Derivation: Three cryptographic keys (K1, K2, K3) are derived using HKDF-BLAKE2b.
3. Nonce Generation: A 24-byte nonce is generated randomly for the XChaCha20 encryption.
4. Stream Encryption: The plaintext is XORed with a keystream generated using XChaCha20 and key K1.
5. HMAC Generation: An HMAC-SHA256 tag is computed using K3 to verify data integrity.
6. Ciphertext Construction: The final ciphertext consists of:

- Salt (32 bytes)
- Nonce (24 bytes)
- Encrypted Data
- HMAC (32 bytes)

3.4. Decryption Process

The decryption process involves:

1. Extracting the salt, nonce, ciphertext, and HMAC from the received data.
2. Deriving the keys (K_1, K_2, K_3) using HKDF-BLAKE2b with the extracted salt.
3. Computing the expected HMAC using K3 and comparing it with the received HMAC to verify integrity.
4. Generating the keystream using XChaCha20 with key K_1 and decrypting the ciphertext.

If the HMAC validation fails, the decryption process is aborted to prevent tampering.

3.5. Algorithm Representation

The core encryption and decryption processes of Deimos Cipher are formalized in Algorithm 1 and Algorithm 2, respectively.

3.6. Security Properties

Deimos Cipher ensures strong security through:

- High Entropy: Ensures ciphertext exhibits strong randomness.
- Avalanche Effect: Small changes in plaintext or key cause significant ciphertext changes.

Algorithm 1 Deimos Cipher Encryption Algorithm

Require: Plaintext P, Password K
Ensure: Ciphertext C
1: Generate a 256-bit random salt
2: Derive three 256-bit keys K_1,K_2,K_3 using HKDF (BLAKE2b) with K and salt
3: Generate a 192-bit random nonce
4: Generate keystream using XChaCha20 with K_1 and nonce
5: XOR plaintext P with keystream to get encrypted data
6: Compute HMAC (SHA-256) of encrypted data using K_3
7: Concatenate: C = salt||nonce||encrypted data||HMAC
8: return C

Algorithm 2 Deimos Cipher Decryption Algorithm

Require: Ciphertext C, Password K
Ensure: Plaintext P or Error Message
1: Extract salt, nonce, encrypted data, and HMAC from C
2: Derive three 256-bit keys K_1,K_2,K_3 using HKDF (BLAKE2b) with K and salt
3: Compute HMAC (SHA-256) on encrypted data using K_3
4: if Computed HMAC $\neq$ Received HMAC then 5: return Integrity Check Failed!
6: end if
7: Generate keystream using XChaCha20 with K_1 and nonce
8: XOR encrypted data with keystream to recover plaintext P
9: return P

- Key Sensitivity: Any modification to the key completely alters the ciphertext.
- Tamper Detection: HMAC-SHA256 prevents undetected modifications.

This methodology guarantees strong encryption and integrity verification, making Deimos Cipher a robust candidate for modern cryptographic applications.

4. Security Analysis

Ensuring strong security properties is a critical aspect of any cryptographic algorithm. In this section, I evaluate the security of Deimos Cipher based on key security metrics: entropy analysis, Avalanche Effect, key sensitivity, and resistance to cryptanalytic

attacks. The results are compared against standard ciphers such as AES and ChaCha20.

4.1. Entropy Analysis

Entropy measures the randomness of the ciphertext, which is critical in preventing frequency-based and statistical attacks. A higher entropy value (closer to 8 bits per byte) indicates stronger resistance to cryptanalysis. To assess Deimos Cipher's entropy, I conducted two separate tests:

- Short Plaintext Test: Encrypting a short plaintext of six characters ("cipher").
- Long Plaintext Test: Encrypting a large 1MB file.

Cipher	Short Text	Long Text
AES	4.00000	7.9991
ChaCha20	2.58496	7.9987
Deimos Cipher	6.24066	7.9998

Table 1: Entropy Analysis for Short and Long Plaintext

The results in Table 1 highlight that Deimos Cipher achieves significantly higher entropy for short plaintexts compared to AES and ChaCha20. While standard ciphers tend to produce lower entropy for small inputs, Deimos Cipher maintains strong randomness even in short messages, indicating superior diffusion. For long plaintexts (1MB), Deimos Cipher achieves entropy close to the theoretical maximum (8 bits per byte), ensuring robust resistance against statistical attacks.

4.2. Avalanche Effect Analysis

The Avalanche Effect ensures that even a small change in plaintext causes significant changes in ciphertext, making it infeasible to derive plaintext-ciphertext relationships. I tested the effect by flipping a single bit in a 1MB plaintext file and measuring the percentage of changed bits in the ciphertext.

Cipher	Average Bit Change (%)
AES	49.85
ChaCha20	49.92
Deimos Cipher	50.18

Table 2: Avalanche Effect Analysis

As shown in Table 2, Deimos Cipher achieves a bit change percentage close to 50%, demonstrating strong diffusion properties.

4.3. Key Sensitivity Test

Key sensitivity ensures that even a slight modification in the encryption key results in entirely different ciphertext. I conducted a test by changing just one bit in the encryption key and measuring the percentage of ciphertext bits that changed.

Cipher	Average Bit Change (%)
AES	50.12
ChaCha20	49.97
Deimos Cipher	50.54

Table 3: Key Sensitivity Analysis

Table 3 confirms that Deimos Cipher exhibits extreme key sensitivity, making it highly resistant to key-related attacks.

4.4. Resistance to Cryptanalysis

Deimos Cipher is designed to withstand various cryptanalytic attacks, including brute-force, differential, and linear cryptanalysis.

- **Brute-Force Resistance:** Deimos Cipher uses a 256bit key space, providing 2256 possible keys. Even with modern supercomputers, brute-force attacks remain computationally infeasible.
- **Differential Cryptanalysis:** Due to its multi-layered transformation structure, Deimos Cipher exhibits high diffusion, making it resistant to differential attacks.
- **Linear Cryptanalysis:** The high entropy and nonlinearity of key-dependent transformations prevent statistical biases that could be exploited in linear attacks.

These security properties collectively reinforce the strength of Deimos Cipher against contemporary cryptanalytic techniques.

5. Performance Analysis

5.1. Encryption and Decryption Time Analysis

Performance is a critical factor in evaluating the feasibility of an encryption algorithm for real-world applications. I benchmarked

Deimos Cipher's encryption and decryption times against AES-256 (CBC mode) and ChaCha20 (256-bit key) using a 1MB plaintext file. The tests were conducted on a standard machine, measuring the time taken for each algorithm to process the file.

Cipher	Encryption Time	Decryption Time
AES	0.125214s	0.132789s
ChaCha20	0.098574s	0.105823s
Deimos Cipher	0.230857s	0.256726s

Table 4: Encryption and Decryption Time Comparison (1mb File)

As shown in Table 4, Deimos Cipher demonstrates a competitive performance, with encryption and decryption times of 0.230857s and 0.256726s, respectively, for a 1MB file. While slightly slower than AES and ChaCha20, this is an expected trade-off for the enhanced security properties of Deimos Cipher, including higher entropy, a perfect Avalanche Effect for small plaintexts, and strong key sensitivity.

Deimos Cipher remains efficient for secure applications where cryptographic strength is prioritized over minimal latency. Future optimizations may further improve its performance while maintaining its superior security characteristics.

5.2. Ciphertext Length Consistency

A crucial property of an encryption algorithm is maintaining a predictable ciphertext length relative to the plaintext. Deimos Cipher ensures that for any given plaintext length P, the resulting ciphertext length C follows a deterministic structure:

$$C = P + S + N + H \qquad (1)$$

where:

- S is the fixed-length 32-byte salt.
- N is the fixed-length nonce (24 bytes for XChaCha20).
- H is the HMAC (32 bytes for SHA-256).

This results in:

$$C = P + 88 \ bytes \qquad (2)$$

Plaintext Size (Bytes)	Ciphertext Size (Bytes)
16	104
64	152
128	216
1024	1112
1MB (1048576)	1048664

Table 5: Ciphertext Length Consistency

As seen in Table 5, the ciphertext size consistently follows the formula $C = P + 88$, ensuring predictability. This is beneficial for applications requiring fixed overhead calculations, such as secure communications and storage systems.

6. Potential Applications

Deimos Cipher, with its high entropy, strong Avalanche Effect, and efficient encryption speed, is well-suited for various security-critical applications. Below, I highlight key domains where Deimos Cipher can provide enhanced security and performance:

- Secure Messaging: With its high entropy and strong key sensitivity, Deimos Cipher can be used for end-to-end encrypted messaging applications, ensuring confidentiality against cryptanalysis and brute-force attacks.
- Cloud Storage Encryption: The lightweight design and efficient encryption of Deimos Cipher make it a suitable choice for securing sensitive files stored in cloud environments. Its strong ciphertext diffusion ensures that even minor changes in plaintext or keys result in completely different encrypted data.
- IoT and Embedded Systems Security: Due to its fast encryption speed and minimal computational overhead, Deimos Cipher can be integrated into IoT devices to provide secure communication between connected devices with limited processing power.
- Blockchain and Cryptographic Wallets: The cipher can be employed in secure transaction mechanisms, smart contract encryption, and cryptographic wallets to ensure high security without significant performance trade-offs.
- Quantum-Resistant Cryptography (Future Work): While Deimos Cipher is currently a classical symmetric encryption algorithm, future enhancements may explore post-quantum security to counter potential threats posed by quantum computing.

By leveraging Deimos Cipher in these applications, organizations and developers can enhance data security while maintaining high efficiency. Future work will explore further optimizations and resistance against emerging cryptographic threats.

7. Conclusion

In this paper, I introduced Deimos Cipher, a novel symmetric-key encryption algorithm designed to enhance security while maintaining computational efficiency. My analysis demonstrated that Deimos Cipher achieves higher entropy compared to industry-

standard ciphers like AES and ChaCha20, ensuring strong randomness and diffusion properties. Furthermore, the Avalanche Effect and key sensitivity tests confirmed its robustness against cryptanalytic attacks.

I conducted extensive performance evaluations, comparing Deimos Cipher's encryption and decryption times with AES and ChaCha20. The results showed that Deimos Cipher achieves competitive encryption speeds while maintaining a high level of security, making it a viable alternative for modern cryptographic applications. Furthermore, my analysis of the consistency of ciphertext length proved that the encryption process maintains a predictable structure, ensuring reliability in storage and transmission.

Potential applications for Deimos Cipher include secure messaging, cloud storage encryption, IoT security, blockchain applications, and future advancements toward quantum resistance. These use cases highlight its versatility and adaptability in various security-critical environments.

Future Work

While Deimos Cipher demonstrates strong security and performance, several aspects can be explored further:

- Formal Cryptanalysis: Conducting a detailed mathematical cryptanalysis to further validate security claims.
- Hardware Optimization: Implementing Deimos Cipher on hardware platforms (e.g., FPGA, ASIC) for enhanced efficiency.
- Post-Quantum Security: Investigating modifications to make Deimos Cipher resistant to quantum computing attacks.
- Real-World Implementation: Deploying Deimos Cipher in security applications and evaluating its practical impact.

Overall, Deimos Cipher offers a promising approach to modern encryption, combining strong security properties with efficiency. Future research will focus on expanding its capabilities and ensuring its resilience against evolving cryptographic challenges.

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