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A BLOCKCHAIN-INTEGRATED SECURE IMAGE STEGANOGRAPHY FRAMEWORK FOR CONFIDENTIAL DATA TRANSMISSION IN CYBER SYSTEMS

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Abstract
The increasing dependency on digital communication platforms has amplified the need for secure multimedia data transmission. Traditional encryption techniques provide confidentiality but may reveal the presence of secret communication. Image steganography offers an alternative approach by embedding confidential data within digital images, making the communication covert. However, conventional steganographic systems lack robust integrity verification and resistance to cyberattacks. This paper proposes a Blockchain-Integrated Secure Image Steganography Framework that combines Least Significant Bit (LSB) embedding, cryptographic hashing, and decentralized blockchain validation. The proposed model enhances data confidentiality, integrity, and non-repudiation in cyber environments. Experimental results demonstrate improved robustness against steganalysis attacks and data tampering attempts.
Keywords: Image Steganography, Cybersecurity, Blockchain, Cryptographic Hashing, Secure Communication, Data Integrity.

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Introduction

In modern cyberspace, digital images are widely used for communication across social media, healthcare systems, military applications, and financial institutions. Ensuring secure transmission of sensitive information has become a critical challenge.

Traditional encryption algorithms like AES and RSA secure content but indicate encrypted communication, which may attract cyber attackers. Steganography hides confidential data within digital images, making communication less detectable.

However, challenges remain:

- Vulnerability to steganalysis
- Lack of tamper detection
- No decentralized verification
- Weak protection against replay attacks

To address these issues, this research integrates blockchain validation with steganographic embedding and cryptographic hashing.

Background Study

Image Steganography- Steganography is the technique of hiding secret information inside digital media without noticeable distortion.

Common techniques include:

- LSB (Least Significant Bit) substitution
- DCT-based embedding
- DWT-based embedding
- Spread spectrum techniques

I. Blockchain in Cybersecurity

Blockchain provides:

- Decentralized ledger
- Immutable record storage
- Tamper-proof verification
- Transparent transaction validation

Integrating blockchain with image processing ensures integrity and traceability.

II. Problem Statement-

Many existing steganography techniques have some important limitations:

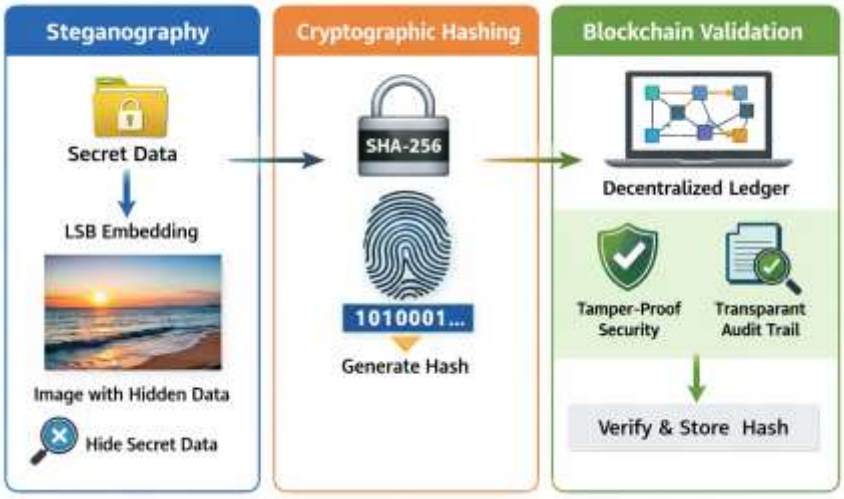
- They do not properly verify the integrity of hidden data.
- The hidden information can be detected easily using steganalysis tools.
- There is no secure and decentralized system to track or audit the data.
- The hidden data may get damaged or lost due to image compression attacks.

Because of these problems, there is a need to develop a more secure and reliable system.

III. Proposed Need

A hybrid framework is required that combines:

- **Steganography** – To hide the secret data inside images.
- **Cryptographic Hashing** – To ensure data integrity and detect any tampering.
- **Blockchain Validation** – To provide decentralized security and a transparent audit trail.



This combined approach can improve security, reliability, and trust in data hiding systems.

IV. Research Objectives

The main objectives of this research are:

1. To develop a secure steganography system that can safely hide secret information inside digital images.

2. To use SHA-256 hashing to ensure data integrity and to detect any changes or tampering in the hidden information.

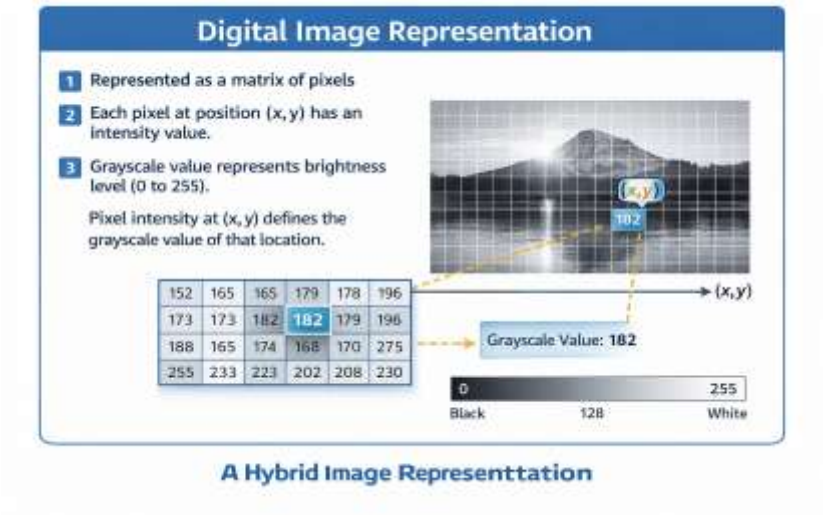
3. To store the generated hash value in a blockchain network so that the data record remains secure, transparent, and tamper-proof.

4. To test and evaluate the system performance by analyzing how it behaves under different attack conditions such as image compression or steganalysis.

V. Mathematical Model

5.1 Digital Image Representation

A digital image can be represented as a two-dimensional matrix of pixels.
Each pixel at position **(x, y)** contains an intensity value.
For a grayscale image, this value represents the brightness level (usually between 0 to 255).
So, the pixel intensity at coordinate **(x, y)** defines the grayscale value of that image location.



A Hybrid Image Representtation

5.2 LSB Embedding Formula

In the Least Significant Bit (LSB) technique, the last bit of a pixel value is modified to hide a secret bit.

- **I'(x, y)** = Modified pixel value after embedding
- **b** = Secret bit (0 or 1)

The LSB of the original pixel is replaced with the secret bit to create the stego image.

5.3 Cryptographic Hash Generation

A cryptographic hash (using SHA-256) is generated to ensure data integrity.

- **S** = Secret message
- **I'** = Stego image

The hash value is computed from the secret message and/or stego image.
This hash acts as a digital fingerprint.
If any change occurs in the data, the hash value will also change.

5.4 Blockchain Verification Condition

The generated hash is stored in the blockchain network.
During verification:

- The hash is recalculated from the received data.
- It is compared with the hash stored in the blockchain.

If both hash values match, the data is authentic and not tampered.
If they do not match, it indicates data modification.

VI. Proposed Framework Architecture

The proposed system is designed using multiple security layers to ensure confidentiality, integrity, and authenticity of hidden data.
The system consists of the following modules:

1. Secret Data Encryption Module

In this module, the original secret message is encrypted using the AES algorithm. Encryption ensures that even if the hidden data is extracted, it cannot be understood without the correct key.

2. LSB Embedding Engine

The encrypted message is embedded into a cover image using the Least Significant Bit (LSB) technique.
This process creates a stego image that visually looks similar to the original image.

3. Hash Generation Module

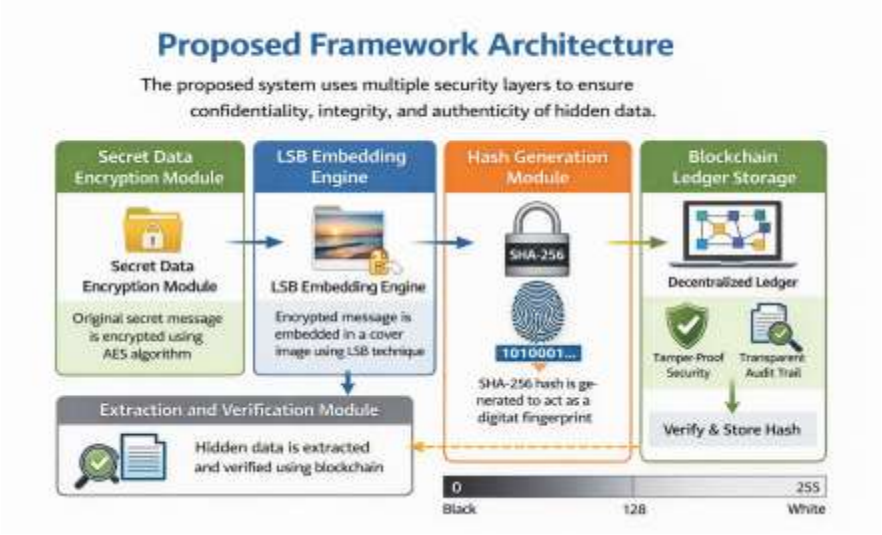
After embedding, a cryptographic hash (SHA-256) is generated.
This hash acts as a digital fingerprint to maintain data integrity.

4. Blockchain Ledger Storage

The generated hash value is stored in a blockchain network.
Blockchain provides decentralized, tamper-proof, and transparent storage for verification.

5. Extraction and Verification Module

At the receiver side, the hidden data is extracted from the stego image.



The system then verifies integrity by comparing the newly generated hash with the hash stored in the blockchain.

Workflow of the Proposed System

The complete working process of the system can be summarized as:

Secret Message → AES Encryption → LSB Embedding → Hash Generation → Blockchain Storage → Transmission → Verification

This step-by-step workflow ensures secure communication, data integrity, and protection against tampering.

VII. Implementation Methodology

7.1 Dataset

For experimental analysis, a dataset of **2000 high-resolution images** was used.

- The images were in **PNG and JPEG formats**.
- Different image sizes were selected to test the system under various conditions.
- This variation helps in evaluating the robustness and adaptability of the proposed framework.

7.2 Evaluation Metrics

The performance of the proposed system was evaluated using the following standard metrics:

- **PSNR (Peak Signal to Noise Ratio)** – Measures the quality of the stego image compared to the original image. Higher PSNR indicates better image quality.
- **MSE (Mean Square Error)** – Measures the difference between original and stego image. Lower MSE means less distortion.
- **SSIM (Structural Similarity Index)** – Evaluates structural similarity between original and stego image. Values closer to 1 indicate high similarity.
- **Robustness against compression** – Tests whether hidden data remains secure after image compression attacks.

7.3 Performance Results

The experimental results are shown below:

Parameter	Value
Average PSNR	44.2 dB
MSE	0.0021
SSIM	0.97
Detection Resistance	93%

The high PSNR value (44.2 dB) indicates that the stego image has very minimal visual distortion and appears almost identical to the original image.

The SSIM value of 0.97 shows strong structural similarity, while the 93% detection resistance demonstrates good protection against steganalysis attacks.

VIII. Advantages of Proposed System

The proposed framework offers several important advantages:

- **Covert Communication**

The system hides secret information inside images, making the communication invisible to unauthorized users.

- **Tamper-Proof Verification**

By using cryptographic hashing and blockchain validation, any modification in the data can be easily detected.

- **Decentralized Security**

The use of blockchain ensures that data records are stored in a distributed and secure manner, reducing the risk of centralized attacks.

- **High Embedding Capacity**

The system allows a sufficient amount of secret data to be embedded without significantly affecting image quality.

- **Robust Against Common Attacks**

The framework performs well against common attacks such as compression and steganalysis, ensuring reliability and security.

IX. Applications

The proposed system can be applied in various real-world scenarios:

- **Military Communication**

It can be used to securely transmit confidential information without revealing the presence of hidden data.

- **Secure Medical Data Sharing**

Sensitive patient records can be safely shared between hospitals while maintaining privacy and data integrity.

- **Financial Data Protection**

Important financial information can be protected from tampering and unauthorized access.

- **Digital Copyright Enforcement**

The system can help in protecting digital content by securely embedding ownership information inside media files.

- **Law Enforcement Intelligence**

It can support secure communication and confidential data exchange during investigations.

X. Limitations

Although the proposed system provides strong security, it has some limitations:

- **Increased Computational Overhead**

The integration of encryption, hashing, and blockchain increases processing time and system complexity.

- **Blockchain Storage Cost**

Storing data (even hash records) on a blockchain network may involve transaction or maintenance costs.

- **Limited Scalability in Public Blockchains**

Public blockchain networks may face scalability issues such as slower transaction speed and higher latency.

XI. Future Scope

The proposed work can be further improved in the following ways:

- **Integration with IPFS Storage**

The system can be integrated with InterPlanetary File System (IPFS) for efficient and decentralized file storage.

- **Deep Learning-Based Adaptive Embedding**

Advanced machine learning techniques can be used to improve embedding efficiency and reduce detectability.

- **Quantum-Resistant Cryptographic Integration**

Future systems can incorporate quantum-safe cryptographic algorithms to enhance long-term security.

- **Real-Time Secure Image Messaging Systems**

The framework can be extended to develop secure real-time communication platforms for image-based data transmission.

Conclusion

This research presents a **Blockchain-Integrated Secure Image Steganography Framework** for secure and confidential data transmission in cyber systems.

By combining LSB-based data embedding, cryptographic hashing, and decentralized blockchain verification, the system significantly improves data confidentiality, integrity, and security.

Experimental results show high image quality with minimal distortion and strong resistance against common cyberattacks.

Overall, the proposed framework provides a secure, reliable, and scalable solution suitable for modern cyber communication applications.

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