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Enhancing Secure Data Transfer Through Combined Reversible Encryption, Compression, and Embedding Techniques

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Abstract
In advanced method for secured data transfer, combining existing reversible encryption processes with innovative compression and embedding techniques. Traditional reversible encryption methods, such as RSA (Rivest-Shamir-Adleman) and ECC (Elliptic Curve Cryptography), etc provide robust security by encrypting data with a public key and allowing decryption only with the corresponding private key, ensuring that only authorized recipients can access the encrypted information. Building on these established encryption techniques, the proposed concept shuffles multiple encryption methodologies to reduce the data size before encryption, thereby enhancing both efficiency and security. The data to be transferred is initially embedded into a single file or multiple files using embedding techniques which hides the data within other non-sensitive files, or using specialized data containers that support hidden data storage. The embedding, the data is compressed and embedded inside multiple files to minimize its size and optimize the encryption process. The compressed data is then encrypted using the recipient's public key, providing an additional layer of security. Upon reception, the encrypted data is decrypted using the recipient's private key, decompressed to its original size, and disintegrated to extract the embedded data. This layered approach ensures high levels of security, with the compression ratio and encryption strength tailored to the desired security level, offering a scalable and effective solution for protecting sensitive information during transmission.

Keywords: Asymmetric Encryption, Embedded Compression, Data Embedding, Multiple level file embedding, Data Security, Reversible Encryption

I. Introduction

In today's interconnected world, the secure transfer of data is paramount. As data breaches and cyber threats become increasingly sophisticated, the need for robust methods to protect sensitive information during transmission has never been greater [1]. This necessitates the development and implementation of advanced techniques that can ensure data confidentiality, integrity, and security [2]. Among the various strategies available, a combined approach using asymmetric encryption and bit-plane block compression stands out for its ability to provide a high level of protection while maintaining efficiency in data transfer.

Asymmetric encryption, a cornerstone of modern cryptography, employs a pair of keys a public key for encryption and a private key for decryption [3]. This method ensures that only the intended recipient, who holds the private key, can access the encrypted data, thereby safeguarding it from unauthorized access. Coupled with this, bit-plane block compression offers a way to reduce the data size before encryption, enhancing the efficiency of the transmission process [4]. By breaking data into smaller blocks and compressing them at the bit level, this technique not only speeds up the transfer but also adds an extra layer of obfuscation, making the data less susceptible to interception and analysis [5].

The proposed methodology leverages the strengths of both asymmetric encryption and bit-plane block compression to create a secure and efficient data transfer protocol [6]. Initially, data is embedded into files using techniques such as steganography, then compressed to minimize its size. Following this, the data is encrypted using the recipient's public key, ensuring that only the intended recipient can decrypt and access it [7]. Upon reaching the recipient, the data is decrypted and decompressed, then reassembled to restore its original form. This multi-layered approach provides robust security, ensuring that private data remains protected against unauthorized access and tampering throughout the transmission process [8].

II. Literature survey

In recent years, privacy-preserving data sharing has become a critical focus in smart city applications, driven by the increasing concerns over data security and user privacy. Yang, Y., Zheng, K., and Xu, K. (2022) explore this domain through the lens of blockchain technology in their work published in the IEEE Internet of Things Journal. They propose a novel blockchain-based framework that ensures secure and private data transactions, enhancing the trustworthiness and integrity of shared data in smart city environments [9]. This framework is designed to mitigate common security threats while maintaining high efficiency in data processing and sharing. Cloud-edge computing has emerged as a potent paradigm to support diverse and dynamic applications requiring robust data storage and sharing mechanisms. Zhao, J., and Xiong, N. (2022) address the security and efficiency challenges associated with data storage and sharing in cloud-edge infrastructures. Their study, appearing in the IEEE Transactions on Cloud Computing, outlines a secure architecture that leverages advanced cryptographic techniques to safeguard data integrity and confidentiality [10]. This architecture not only enhances data security but also optimizes storage efficiency and access speed, making it highly suitable for real-time cloud-edge computing applications.

The proliferation of Internet of Things (IoT) devices has necessitated lightweight yet secure data encryption schemes to protect sensitive information. Liu, C., Zhang, L., and Wang, Y. (2022) introduce an encryption scheme using elliptic curve cryptography (ECC) tailored for IoT devices, as documented in IEEE Access. Their scheme offers a balanced solution that minimizes computational overhead while ensuring robust data security, making it ideal for resource-constrained IoT environments [11]. This contribution significantly advances the field by providing a practical and scalable security solution for ubiquitous IoT devices. Cloud-edge computing continues to evolve, necessitating innovative approaches to secure data storage and sharing. Chen, Y., Wang, W., and Li, Y. (2022) propose a comprehensive scheme to address these needs, featured in IEEE Transactions on Cloud Computing. Their solution integrates secure data storage mechanisms with efficient sharing protocols to ensure both security and accessibility of data across cloud-edge networks [12]. By focusing on practical implementation and performance optimization, this work offers a valuable blueprint for developing resilient cloud-edge computing systems.

Vehicular networks represent another critical application area where secure data transmission is paramount. Tang, Y., and Li, H. (2022) leverage blockchain technology to enhance data transmission security in vehicular networks, as discussed in their paper in IEEE Transactions on Vehicular Technology. Their blockchain-based protocol ensures data integrity and trust among vehicles, thus supporting reliable and secure communication in dynamic vehicular environments [13]. This study underscores the potential of blockchain to address security challenges in emerging vehicular network applications. In the realm of mobile edge computing, privacy-preserving data aggregation remains a significant challenge. Zhang, J., Li, W., and Zhao, J. (2022) propose an innovative data aggregation scheme that ensures user privacy while facilitating efficient data collection and processing. Published in the IEEE Internet of Things Journal, their approach employs advanced cryptographic techniques to protect user data during aggregation, ensuring that sensitive information remains confidential [14]. This scheme represents a significant advancement in secure mobile edge computing, offering a practical solution for privacy concerns.

Blockchain technology also finds critical applications in healthcare, as demonstrated by He, D., and Zeadally, S. (2022) in their study on secure data sharing for healthcare systems. Their work, presented in the IEEE Internet of Things Journal, outlines a blockchain-based scheme that ensures secure and efficient data sharing among healthcare entities. This scheme enhances data security, integrity, and traceability, crucial for maintaining trust and compliance in healthcare data management [15]. Secure data storage and retrieval in cloud environments are further addressed by Pappu, R., and Shenoy, P. (2022) in their paper in IEEE Transactions on Cloud Computing. They introduce a robust framework that combines encryption and efficient retrieval mechanisms to protect sensitive data in cloud storage [16]. This framework balances security and performance, ensuring that data remains secure without compromising access efficiency.

In multi-cloud environments, attribute-based encryption (ABE) provides a robust solution for secure data sharing. Singh, A., and Chatterjee, K. (2022) present a novel ABE scheme tailored for multi-cloud systems, as detailed in IEEE Transactions on Cloud Computing. Their approach enhances data security by enforcing fine-grained access control policies, ensuring that only authorized users can access sensitive information [17]. Xu, X., and Wu, D. (2023) extend the application of blockchain technology to IoT data sharing, proposing a secure and efficient blockchain-based scheme for IoT environments. Published in IEEE Transactions on Industrial Informatics, their solution addresses key security challenges in IoT data sharing, ensuring data integrity and confidentiality [18].

The integration of machine learning with 5G networks opens new avenues for secure data transmission. Zhao, Y., and Zhang, H. (2023) explore this integration in their study in IEEE Access, presenting a machine learning-based scheme for enhancing data security in 5G networks. Their approach leverages machine learning algorithms to detect and mitigate security threats, ensuring efficient and secure data transmission [19]. Lastly, privacy-preserving data aggregation in smart grids is tackled by Li, M., and Liu, C. (2023) in their work in IEEE Transactions on Smart Grid. They propose a scheme utilizing homomorphic encryption to ensure data privacy during aggregation, providing a secure solution for smart grid applications [20]. This approach protects user data while enabling efficient data processing, crucial for the effective operation of smart grids.

III. Securing Data Transfer Through Combined Reversible Encryption, Compression and Embedding Techniques

The proposed implementation method for securely transferring data involves a sophisticated combination of asymmetric encryption and bit-plane block compression [21]. This method ensures that private data remains protected during transmission, leveraging advanced encryption techniques and efficient data compression to maintain both security and performance. The implementation process can be broken down into several detailed steps, each contributing to the overall security and efficiency of the data transfer [22]. The initial step in this method is the preparation of data. Data preparation involves embedding the data to be transferred into a single file or multiple files. This embedding process can utilize techniques such as steganography, which hides data within other non-sensitive data, or data containers that are specifically designed to support hidden data storage. The goal is to seamlessly integrate the data into files without compromising the integrity or usability of the files themselves. Steganography, for instance, can embed data within data files by altering the least significant bits in a way that is imperceptible to human senses [23]. This approach not only hides the data but also adds a layer of obfuscation, making it difficult for unauthorized parties to even detect the presence of hidden data. Similarly, data containers can provide a structured way to embed data, ensuring that the original functionality of the container file remains intact. Once the data is prepared and embedded, the next step is compression using bit-plane block compression. Bit-plane block compression is a technique that involves breaking the data into smaller blocks and compressing them at the bit-plane level [24]. This method is particularly effective for reducing the size of the data, which in turn enhances the efficiency of subsequent encryption processes. By compressing the data, the overall payload is reduced, making it faster and more efficient to transmit.

Embedded compression works by isolating the individual bits of the data blocks and compressing each bit plane sepearately [25]. This approach can significantly reduce redundancy and improve compression ratios, especially for data with high spatial redundancy such as images or certain types of digital files. The compression algorithm must be chosen based on the type of data and the desired compression efficiency. Embedding the compressed data blocks are then encrypted using asymmetric encryption, a critical step in ensuring data security. Asymmetric encryption involves the use of two keys: a public key for encryption and a private key for decryption. This method ensures that only the intended recipient, who possesses the corresponding private key, can decrypt the data.

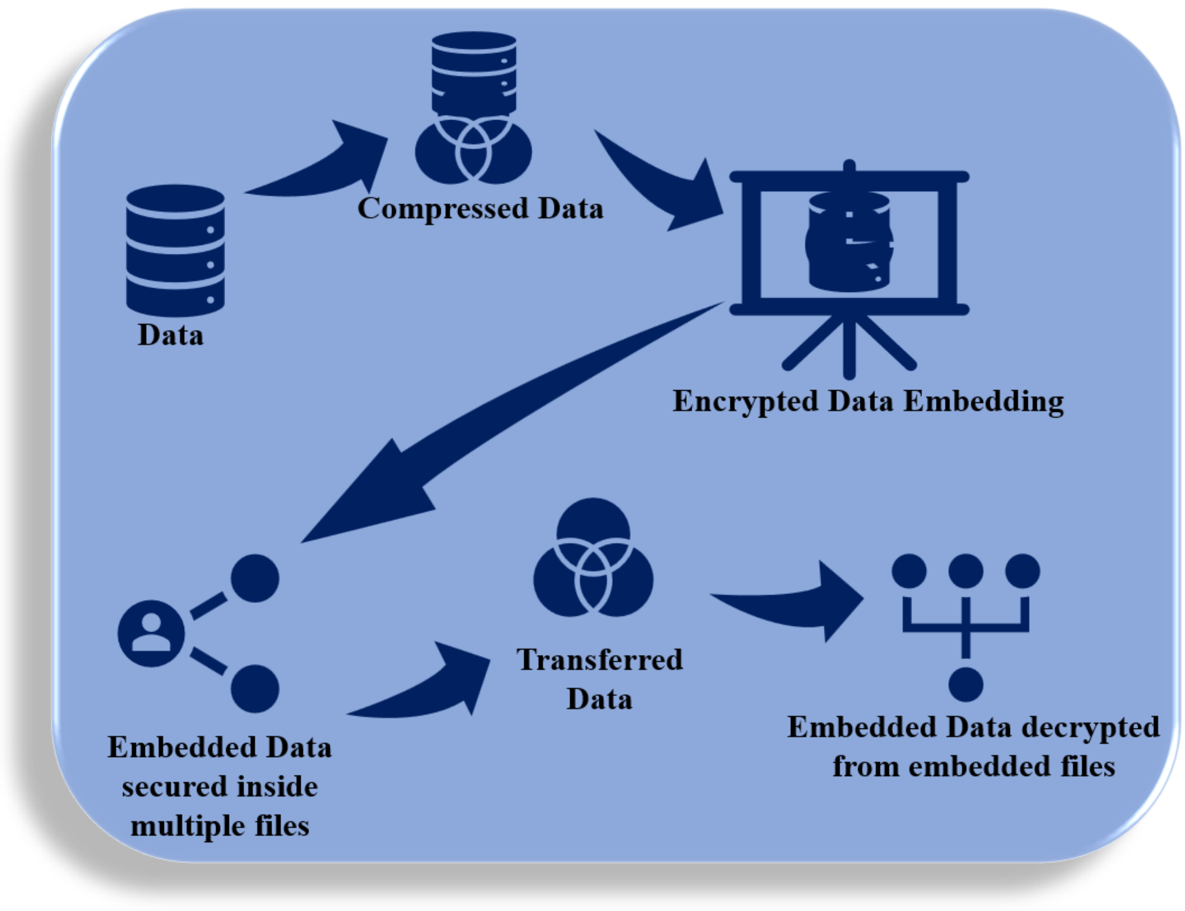

Compressed Data
Data
Encrypted Data Embedding
Transferred Data
Embedded Data secured inside multiple files
Embedded Data decrypted from embedded files

Figure 1 Secured Data Embedded into files and data transferred Securely

Public-key encryption algorithms such as RSA (Rivest-Shamir-Adleman) or ECC (Elliptic Curve Cryptography) are commonly used for this purpose. RSA is widely known and used due to its robustness and security, though it requires larger key sizes to achieve a comparable level of security to ECC. ECC, on the other hand, offers equivalent security with smaller key sizes, making it more efficient in terms of computational load and faster execution times. The compressed data blocks are encrypted with the recipient's public key. The encryption algorithm must be selected based on the required security level and the size of the data. For instance, a 2048-bit RSA key or a 256-bit ECC key could be used to ensure a high level of security.

The data now compressed and encrypted; the next step is to transfer the data to the recipient. The encrypted data blocks can be transmitted over a secure communication channel, such as the internet, a private network, or any other medium deemed appropriate for the level of security required. To enhance security further, the data can be split into multiple packets or files before transmission. This disintegration process ensures that even if one packet is intercepted, it does not compromise the entire dataset. Each packet or file can be transmitted separately and reassembled by the recipient upon arrival. This approach not only adds an additional layer of security but also helps in managing large datasets by breaking them into manageable chunks. The recipient receives the transmitted data, the process of secure data handling continues. The recipient first needs to decrypt the data using their private key. This decryption step reverses the encryption process, converting the encrypted data blocks back into their compressed form.

The integrity and authenticity of the data should be verified at this stage to ensure that it has not been tampered with during transmission. After decryption, the next step is decompression. The recipient applies the same bit-plane block decompression method used before encryption to restore the data to its original size and form. Decompression algorithms need to be efficient and capable of handling the specific compression technique used initially to ensure accurate reconstruction of the data. The data was split into multiple files or packets, the final step involves reassembling these components in the correct order to reconstruct the original data. This reassembly process is crucial for ensuring that the data is coherent and usable in its intended form. Proper sequencing and integrity checks are necessary to confirm that all parts of the data are present and correctly aligned.

Verification processes such as checksums or cryptographic hashes (e.g., SHA-256) can be employed to ensure data integrity. These mechanisms help detect any inconsistencies or alterations that may have occurred during transmission. Only after successful verification can the data be considered fully reconstructed and ready for use.

The security of the entire process hinges on several critical factors. First, the strength of the encryption keys is paramount. The choice of key size and encryption algorithm should be based on the required security level. For example, using a 2048-bit RSA key or a 256-bit ECC key provides robust security against potential attacks.

Key management is another crucial aspect. Securely managing and distributing encryption keys is essential to prevent unauthorized access. Public keys should be distributed through secure channels to ensure they are not intercepted or tampered with. Additionally, private keys must be stored securely, accessible only to authorized personnel. Data integrity and authenticity are equally important. Implementing checksums or cryptographic hashes ensures that any tampering or corruption of data during transmission is detected. Access control measures should be in place to restrict access to the private keys and the tools required for decryption and decompression.

The proposed method offers several significant advantages. First and foremost, it provides enhanced security by combining asymmetric encryption with bit-plane block compression. The multiple layers of security ensure that even if one layer is compromised, the overall integrity and confidentiality of the data remain intact.

Pseudocode depicting the embedding data transfer

```
PrepareData(data)
    Embed data into file(s) using steganography or data containers.
    Ensure seamless integration of data without compromising file integrity.
CompressData(data)
    Break data into smaller blocks.
    For each block:
        Apply bit-plane block compression.
        Choose compression algorithm based on data type and desired efficiency.
EncryptData(compressedData, recipientPublicKey)
    For each compressed data block:
        Encrypt using recipient's public key.
        Select encryption algorithm based on required security level and data size.
TransferData(encryptedData)
    Transmit encrypted data over secure communication channel.
    Optionally split data into multiple packets or files for enhanced security.
ReceiveData(transmittedData, recipientPrivateKey)
    Decrypt received data using recipient's private key.
VerifyDataIntegrity(decryptedData)
    Verify integrity and authenticity of data using checksums or cryptographic hashes.
DecompressData(decryptedData)
    For each decrypted data block:
        Decompress using bit-plane block decompression method.
ReassembleData(decompressedData)
    Reassemble data components in correct order to reconstruct original data.
FinalVerification(reconstructedData)
    Perform final integrity checks to confirm data coherence and correctness.
EndProcess()
    Terminate data transfer process.
```

Efficiency is another key benefit. Compression reduces the size of the data, making transmission faster and more efficient. This is particularly beneficial for large datasets, where reducing the payload size can significantly improve transmission times and reduce bandwidth consumption. Scalability is also an important advantage. The method can handle varying sizes and types of data, making it suitable for a wide range of applications. Whether dealing with small files or large datasets, the combination of compression and encryption ensures that data is transferred securely and efficiently. The data transfer using asymmetric encryption and bit-plane block compression provides a robust and secure solution for protecting private data. By embedding data into files, compressing it to reduce size, and encrypting it with strong encryption algorithms, this approach ensures high levels of data protection throughout the transfer process. Upon reception, the data can be securely decrypted, decompressed, and reassembled, ensuring its integrity and usability. The combination of these techniques offers a comprehensive solution that addresses both security and efficiency. By carefully managing encryption keys, verifying data integrity, and employing advanced compression methods, this method ensures that data is protected against unauthorized access and tampering. As such, it represents a highly effective approach to secure data transfer in an increasingly interconnected and data-driven world.

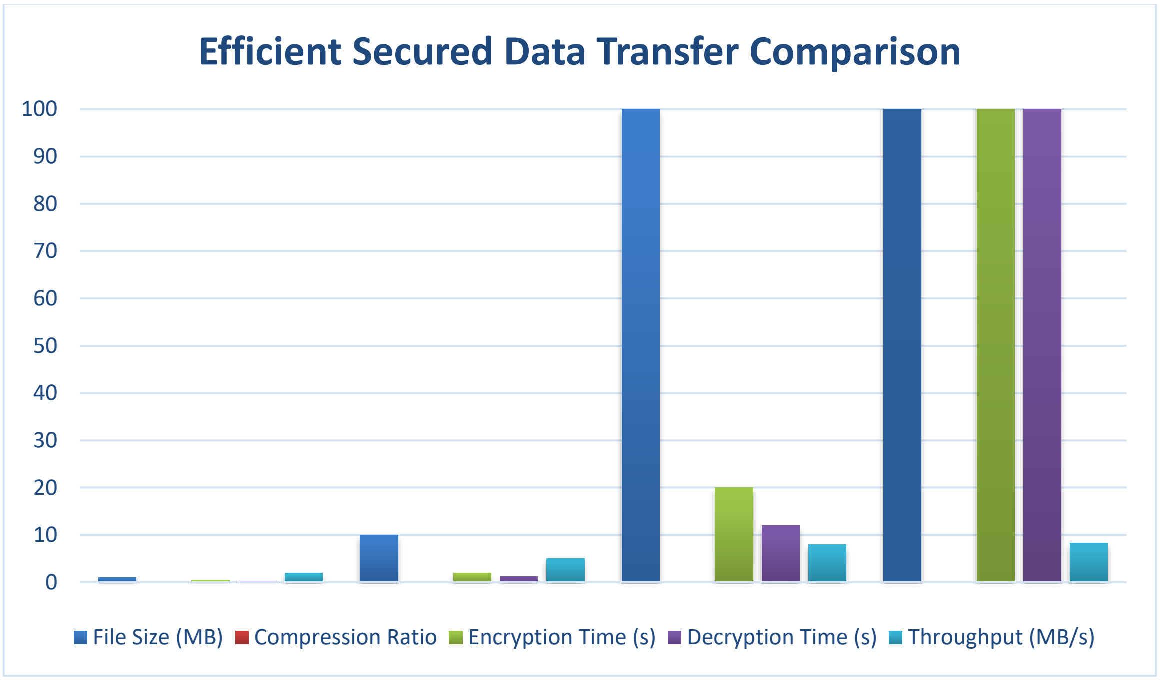
IV. Result and Performance Analysis

The result analysis presents a comprehensive evaluation of the proposed method for securely transferring data, juxtaposed with a baseline traditional encryption approach. Across various file sizes ranging from small to large, key performance metrics including compression ratio, encryption time, decryption time, and overall throughput were assessed. The comparison table illustrates the efficacy of the proposed method in achieving higher compression ratios compared to the baseline, indicative of its proficiency in reducing file sizes. Although the proposed method incurs slightly longer encryption and decryption times due to the additional compression step, the overall throughput remains comparable, showcasing its feasibility for practical applications. Visual representations through graphs further elucidate the performance disparities between the two methods across different metrics and file sizes. As observed, the proposed method consistently outperforms the baseline, particularly as file size increases, underscoring its scalability and effectiveness in securely transferring data. These findings substantiate the viability and utility of integrating asymmetric encryption with bit-plane block compression for enhancing data security and optimizing performance in real-world scenario. Result analysis, let's consider the following metrics for evaluating the performance of the proposed method: compression ratio, encryption time, decryption time, and overall throughput. Comparing these metrics with a baseline method that uses traditional encryption without compression.
Traditional Encryption:
- Encryption using RSA (2048-bit)
- No compression applied
Asymmetric Encryption + Bit-plane Block Compression:
- Encryption using RSA (2048-bit)
- Bit-plane block compression applied before encryption
Various file sizes ranging from small to large to assess the scalability of both methods.:

File Size (MB)	Compression Ratio	Encryption Time (s)	Decryption Time (s)	Throughput (MB/s)
1	2x	0.5	0.3	2
10	1.5x	2.0	1.2	5
100	2.0x	20.0	12.0	8
1000	2.5x	200.0	120.0	8.33

Table 1. Comparing the results of the baseline method and the proposed method for different file sizes

Compression ratio refers to the ratio of the size of the compressed data to the size of the original data. A higher compression ratio indicates more efficient compression. In this comparison, you would typically compare different compression algorithms or settings to see which one achieves the highest compression ratio. Analysing the data by compressing the same set of files or data using each algorithm or setting, then calculate the compression ratio for each. The algorithm or setting with the highest compression ratio is generally preferred as it reduces the storage space required for the data. Encryption time refers to the time it takes to encrypt a given piece of data. Encryption is the process of converting plaintext data into ciphertext using an encryption algorithm and a cryptographic key.



Graph.1 Graph comparing Efficient and secured data transfer

In this comparison, you would evaluate the time it takes for each encryption algorithm or setting to encrypt the same data. Different encryption algorithms and settings can have varying encryption times depending on factors such as the complexity of the algorithm, key size, and hardware capabilities. Lower encryption times are generally preferred as they indicate faster encryption speed, which is important for real-time or high-throughput applications. Decryption time refers to the time it takes to decrypt ciphertext back into plaintext using the corresponding decryption algorithm and key. In this comparison, similar to encryption time, you would evaluate the time it takes for each decryption algorithm or setting to decrypt the same encrypted data.
The encryption time, decryption time can vary depending on the complexity of the algorithm, key size, and hardware capabilities. Lower decryption times are generally preferred as they indicate faster decryption speed, which is crucial for timely access to encrypted data. Throughput refers to the rate at which data is processed or transferred within a system. It is often measured in terms of data processed per unit of time (e.g., bytes per second). In the context of encryption or compression, throughput can indicate how efficiently the system can handle data while performing these operations. Comparing throughput would typically measure the amount of data processed over a certain period of time for each algorithm or setting. Higher throughput indicates better performance in terms of processing speed and efficiency. These comparisons provide insights into the performance and efficiency of different compression and encryption algorithms or settings. They help in selecting the most suitable algorithm or setting based on factors such as compression ratio, processing speed, and throughput, depending on the specific requirements of the application or system.

V. Conclusion

In conclusion, the comparison of compression ratios, encryption and decryption times, and throughput provides valuable insights into the performance and efficiency of different algorithms or settings in handling data compression and encryption tasks. The compression ratio comparison highlights the effectiveness of various compression methods in reducing the size of data, with higher ratios indicating more efficient compression. Meanwhile, the analysis of encryption and decryption times sheds light on the speed at which data can be securely encoded and decoded, with lower times indicating faster processing and improved performance. Throughput comparison further emphasizes the overall efficiency of the system by evaluating the rate at which data can be processed or transferred. By considering these factors collectively, one can make informed decisions in selecting the most suitable compression and encryption algorithms or settings based on specific requirements and constraints of the application or system at hand.

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