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AES, DES, and RSA in Data Security: A Review

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ABSTRACT
In today's digital age, protecting the confidentiality, integrity, and security of data is a major concern. Cryptography is essential for safeguarding information from malicious attacks by using symmetric and asymmetric encryption methods. The most commonly used algorithms are AES (Advanced Encryption Standard), DES (Data Encryption Standard), and RSA (Rivest-Shamir-Adleman). This review paper offers a comparison of these algorithms based on performance, security, and efficiency. Existing studies show that AES delivers better encryption speed and efficiency, while DES uses more CPU resources. RSA is a very secure algorithm, but it requires more memory. To overcome the limitations of these algorithms, hybrid encryption methods have been suggested, which combine symmetric and asymmetric techniques. For example, AES-RSA hybrid encryption uses the speed of AES for encrypting data and the strength of RSA for securing keys. Triple hybrid methods (AES, DES, RSA) improve performance and security by reducing CPU and memory use. The findings from the studies reviewed highlight the benefits and drawbacks of each method. They show that hybrid encryption is a strong choice for enhancing data security in areas like online transactions, file transfers, and secure communications.

Keywords: Information Security, Cryptography, AES, DES, RSA, Hybrid Encryption, Data Protection

I. INTRODUCTION

One of the most common methods used to protect data is cryptography. Based on mathematical algorithms, it converts plaintext into unreadable ciphertext, accessible only by authorized users. The two broad types of cryptographic algorithms are symmetric encryption and asymmetric encryption. Symmetric algorithms such as DES (Data Encryption Standard) and AES (Advanced Encryption Standard) use a single secret key both for encryption and decryption. They are efficient with processing large amounts of data, but inefficient with securely sharing keys. Asymmetric algorithms, on the other hand, employ a pair of public and private keys, such as RSA (Rivest–Shamir–Adleman). While this approach tends to be slower and more processor-hungry, it is more secure when sharing keys. Although every algorithm has its advantages, none provides an overall solution. AES is fast and reliable but susceptible to key management vulnerabilities. DES, also a widely used single-use encryption algorithm, has been considered insecure because of the smaller key size and susceptibility to brute-force attacks. RSA, although secure to use for exchanging keys, is costly in computation when used for encrypting big data sets. All these vulnerabilities have encouraged scientists to find hybrid encryption techniques.. They draw on the strengths of both symmetric and asymmetric methods. For example, symmetric algorithms such as AES perform bulk data encryption for performance, whereas

asymmetric algorithms such as RSA encrypt the symmetric keys so that communication is secured. Triple hybrid encryption (AES + DES + RSA) is recommended by some studies to balance both security and performance. The review paper presents a comparison between AES, DES, and RSA encryption algorithms individually as well as in their hybrid forms. It examines their performance in relation to execution time, CPU and memory usage, throughput, and security levels. It also addresses benefits and limitations of hybrid encryption approaches to solving modern data security challenges. Through the combination of findings from literature, the review aims to clarify classical and hybrid crypto schemes, uses, and potential for further development

II. LITERATURE REVIEW

In recent studies, there has been great emphasis on analysing and comparing various cryptographic algorithms to understand better how they can perform and where they have an edge or are weak. There are several studies pointing out the speed-security trade-off while making a choice
between symmetric and asymmetric methods. For example, AES is always in the
top-performing algorithms when it comes to handling large data because of its high
speed and low overhead in computations, while RSA and ECC are typically referenced for their strong security guarantees, particularly in key management and authentication.

Researchers have been developing hybrid cryptographic techniques that combine the good aspects of symmetric and asymmetric approaches. They are particularly important in securing communication in insecure conditions like the Internet of Things (IoT), where processing power and storage in devices are typically lacking. By combining the high speed of AES with the secure key exchange of RSA or ECC, hybrid systems provide improved security against attacks such as poor authentication and insecure communication channels

There is also increased interest in pushing cryptography to applications beyond conventional implementations. There is some recent research in blending encryption with next-generation methods like machine learning, especially for use in smart grids and real-time data protection. Such methods prove that cryptography might not be enough when it comes to combating new-generation cyberattacks and that their implementation in conjunction with intelligent detection systems can hugely improve overall system security.

A second emphasis has been on head-to-head comparison of hybrid blends of algorithms. Research comparing AES, DES, and RSA both in solo mode and when combined together indicates that AES is
still the fastest for encryption and decryption, and RSA generally requires greater memory usage. Surprisingly, when these algorithms are combined into hybrid
systems, especially multi-level systems, their effect on performance can be avoided or significantly reduced, giving an overall better trade-off between speed, memory usage, and security.
Generally, the literature seems to indicate a consensus that although AES and RSA remain highly trusted standards, the future of secure communications is in hybrid and adaptive cryptographic algorithms These methods provide not only efficiency but also the amount of robustness required to survive ever more sophisticated cybersecurity attacks.

III. COMPARATIVE ANALYSIS AND DISCUSSION

This section synthesizes empirical and review evidence on AES, DES, and RSA from a selection of recent comparative and hybrid studies. The goals are to (1) compare these algorithms along technical and operational parameters, (2) identify consensus and disagreements across studies, and (3) draw practical recommendations for file/image encryption and hybrid designs.

3.1 Technical specifications (concise reference)

Algorithm	Typical key sizes	Block size	Typical rounds	Type
AES	128 / 192 / 256 bits	128 bits	10 / 12 / 14	Symmetric block cipher
DES	56 bits (effective)	64 bits	16	Symmetric (legacy)
RSA	1024 / 2048 / 3072 / 4096 bits (modulus)	—	(asymmetric ops)	Public-Key Crypto-system

(These parameters are standard and repeated across surveyed material.)

3.2 Security comparison (what the literature collectively reports)

AES:

Consensus: AES is the recommended modern symmetric cipher for bulk data — secure against known classical attacks when correctly implemented and using recommended key sizes. Multiple comparative reviews and surveys reiterate AES's strong security profile.

DES:

Consensus: DES is obsoleted because it has a 56-bit key and is vulnerable to brute-force; 3DES enhances security but at high-performance penalty and is also being phased out in favor of AES. A number of reviews describe DES/3DES as legacy algorithms best replaced by AES.

RSA:

Consensus: RSA remains critical for public-key tasks — key exchange, authentication, digital signatures — but it is inefficient for encrypting large data payloads. Most empirical comparisons show RSA's computational and memory overhead grows rapidly with key size; moreover, quantum algorithms threaten RSA in the long run, motivating interest in ECC and post-quantum schemes.

Synthesis: AES for bulk data; RSA for key management/signatures; avoid DES for new systems. Hybrid AES+RSA remains the practical standard.

3.3 Performance (execution time, memory, CPU) — cross-paper synthesis

Across the empirical papers and comparative surveys the performance pattern is consistent:

Encryption speed: AES outperforms DES and vastly outperforms RSA for bulk encryption. Papers that ran benchmarks on files/images report AES lowest encryption/decryption latency; RSA is slowest when used to protect data directly.

Memory usage: The key generation and expansion processes of RSA require larger memory footprints. AES exhibits moderate memory usage and profits significantly from hardware support (AES-NI).

CPU usage: RSA is CPU-intensive (particularly with >2048-bit keys); DES implementations in some older experiments exhibit higher relative CPU due to less optimized code paths; AES is usually most CPU efficient on current implementations.

Notable experimental observations from the collected literature:

Hybrid tests (AES encrypt data + RSA encrypt AES key) show near-AES throughput while providing secure key distribution — an observation consistently reported in hybrid papers and benchmark studies.

A few newer studies (including some IoT-focused work) show ECC + AES hybrids perform better than RSA + AES when resource constraints are tight (ECC gives similar security with smaller key sizes).

3.4 Applications (where each algorithm is most appropriately applied)

AES — File encryption, disk encryption, TLS data payload, cloud storage, streaming media, high-

throughput systems. AES is a suitable fit for server and edge devices with AES-NI/ARM Crypto because of hardware acceleration.
DES — Legacy support only; use AES where possible.
RSA — Key exchange, digital signatures, certificate-based authentication, PKI infrastructure; used to encrypt symmetric keys instead of payloads.
Hybrid AES+RSA/ECC — Preferred architecture for secure file transfer, encrypted email, and cloud storage in order to balance encryption performance with secure key management. ECC is preferred for resource-constrained devices.

3.5 Strengths and weaknesses (compact table)

Algorithm	Strengths	Weaknesses
AES	Fast, secure (128/192/256), hardware acceleration	Symmetric key distribution; quantum concerns in long-term
DES	Historically simple, educational	Insecure (56-bit); deprecated
RSA	Asymmetric features: secure key exchange & signatures	Slow for bulk data; high CPU/memory; quantum-vulnerable

(Consensus statement across multiple comparative and empirical papers.)

3.6 Insights from the expanded literature (10+ additional papers)
After reviewing additional comparative and hybrid studies (examples include empirical speed/memory comparisons, cloud-focused hybrid proposals, and IoT energy-aware hybrid work), the following patterns are clear:
Reproducibility gap: Many studies use different datasets, block modes (ECB/CBC/GCM), and hardware (Google Collab, laptops, IoT boards) — this complicates direct numeric comparison. Several authors call for a standardized benchmark.
Mode and padding are important: The cypher mode (CBC vs. GCM) and implementation specifics (e.g., Python vs. C with OpenSSL) affect the reported speed/security trade-offs. Papers that provided carefully controlled experiments (JETIR, Özer & Aydos) give the clearest, comparable results.
Emerging alternatives: ECC appears frequently as a practical asymmetric replacement to RSA in resource constrained setups; research into lattice-based and other post-quantum KEMs is increasing.
Hybrid is best practice: Practical implementations (cloud, secure file transfer, TLS) use symmetric payload encryption with asymmetric key encapsulation — all surveyed applied papers recommend this pattern.

3.7 Recommendation Statement
Based on the literature reviewed, AES-256 is recommended for payload encryption, ideally with AES-GCM for integrity and authenticity. The AES session key must be securely transported using RSA-2048/3072 or ECC (e.g., secp256r1), with ECC being desirable in resource-limited environments. Hybrid AES + RSA/ECC is the best current practice for secure file and image encryption.

IV. APPLICATION AND USE CASES

Encryption algorithms discussed in this paper (AES, DES, RSA, and hybrid techniques) are used in a wide range of fields. This section outlines common and indispensable use cases and why specific algorithms or hybrid schemes are used in each context.

4.1 Cloud Storage and Backup
Cloud storage systems require both high-throughput encryption and strong key management. AES (typically AES-256 with authenticated modes such as AES-GCM) is used for encrypting files and object storage due to its speed and low CPU overhead; RSA or ECC is used to encrypt keys and manage access via PKI. Hybrid AES+RSA (or AES+ECC) is therefore the standard approach for secure cloud storage.

4.2 Secure File Transfer and Email
Secure file transfer products and encrypted email are based on symmetric encryption for the body of the message (AES) and asymmetric encryption (RSA or ECC) for key exchange and digital signatures. S/MIME and PGP protocols utilize hybrid approaches to provide confidentiality, integrity, and non-repudiation.

4.3 Web Security (TLS / HTTPS)
Transport Layer Security (TLS) applies asymmetric cryptography in the handshake (RSA/ECDHE) for key exchange and authentication and then symmetric ciphers (AES-GCM, ChaCha20-Poly1305) for the session payload in order to provide both security and performance. Current implementations of TLS prefer AEAD modes in order to obtain combined confidentiality and integrity.

4.4 Disk / Full-Drive Encryption
Disk encryption products (such as BitLocker, LUKS) most often employ AES in XTS or CBC mode for full-disk encryption. AES hardware acceleration (AES-NI) significantly improves performance for such use cases.

4.5 IoT and Constrained Devices
Internet-of-Things (IoT) devices often have severe CPU and memory constraints; here, hybrid solutions using AES for payloads and ECC for key exchange (instead of RSA) are common because ECC provides equivalent security with smaller keys.

Where AES is too complex, specific lightweight ciphers and lightweight authenticated data encryption modes are also used.

4.6 Critical Infrastructure and Smart Grids
Systems that require real-time performance
and high integrity (eg smart networks) can use high-throughput links for safe main distribution and AES for hybrid mechanisms; Some studies recommended connecting AE with an intrusion detection and anomaly detection system to protect against injection attacks or tampering.

V. CHALLENGES AND FUTURE RESEARCH DIRECTIONS

Even with widely adopted standards, literature identifies many open problems and active research directions. This section emphasizes the most important issues you should mention and consider in your review papers.

5.1Standardized Benchmarking and Reproducibility
Many studies use different data sets, file sizes, mode (ECB/CBC/GCM) and design platforms, making direct comparison difficult. There is a clear requirement for a standardized benchmarking suite (fixed dataset, hardware profile, cipher mode), so the reports of future studies report comparable metrics (encryption time, throughput, CPU%, memory, energy). Cover this difference and suggest a reference plan if you propose future work.

5.2Post-Quantum Cryptography (PQC) RSA and ECC face theoretical threats from the quantum algorithms (noise algorithms). Recent research has insisted on integrating the PQC (e.g. lattice-based KEMs) with

symmetric ciphers such as AEs in hybrid frames, and assessed the defined performance. You should recommend that the future hybrid design evaluate PQC KEMS (key exchange) for key exchange instead of RSA/ECC

5.3Lightweight and Energy-Efficient Cryptography
IoT, sensor networks, and battery-powered devices need cryptographic schemes tailored for low-energy and computation-constrained environments. Lightweight authenticated ciphers, hardware acceleration of AES on microcontrollers, and ECC optimizations are areas of active research. Propose tests in energy usage and

throughput for AES versus lightweight ciphers on representative platforms

5.4 Integration with AI/ML Security Pipelines
Since AI/ML systems handle high volumes of sensitive information, there is an increasing necessity to research how encryption impacts model training, inference latency, and privacy-preserving protocols (e.g., encrypted inference, federated learning with encrypted gradients). Research such as algoTRIC identifies this intersection as a rich research area.

5.5 Multi-layer (Triple-Hybrid) Schemes: Cost vs. Benefit
Some experimental works try triple-hybrid combinations (AES + DES + RSA) and find subtle advantage in layered defense. But this comes at a cost of overhead and complexity. Suggest targeted research that warrants multi-layer use only for extreme threat domains (military, high-value financial networks).

5.6 Usability and Key Management
Secure key lifecycle management (generation, exchange, rotation, revocation) continues to be an operational challenge. Studies should solve automated, usable key management schemes and bake them into
hybrid encryption protocols with little risk of human error.

VI. RECOMMENDATIONS (PRACTICAL TAKEAWAYS)

From the literature reviewed and comparative assessment, the following practical recommendations are made for document and image encryption projects:

Payload Encryption: Use AES-256 for encrypting data, ideally with authenticated modes like AES-GCM to offer confidentiality as well as integrity. ChaCha20-Poly1305 can be used as an alternative authenticated cipher in certain scenarios.

Session Key Protection: Transmit the AES session key securely via the use of RSA (2048/3072-bit) or ECC (e.g., secp256r1), depending on computational and memory resources available on the target devices. ECC should be used in resource-scarce environments due to its shorter key sizes. and lower computational overhead

Benchmarking and Reproducibility: Perform benchmark tests ". documenting CPU, RAM, OS, library versions, and cipher mode "to ensure the reproducibility of results.
Future-Proofing Consider the future impact
of quantum computing by researching post-quantum cryptography (PQC) key encapsulation mechanisms (KEM and consider hybrid PQC-AES schemes for
future-proof designs.
Legacy Algorithms: Don't use DES and 3DES in new structures. Refer to them best in historical context or whilst discussing legacy migration situations.

VII. CONCLUSION

This review has evaluated hybrid information security techniques by combining effects from numerous comparative and empirical research. The main findings are:

AES is the preferred symmetric algorithm for bulk encryption because of its strong protection and performance.

RSA remains fundamental for asymmetric tasks (key exchange, signatures) however is impractical for encrypting huge payloads; ECC is a viable alternative for restricted devices.

Hybrid schemes (AES RSA/ECC) provide an excellent real-world trade-off between overall performance and protection and are recommended for secure document and image encryption.

Future work must address benchmarking standardization, post-quantum migration, and energy-efficient cryptography for IoT.

These conclusions align with the predominant studies surveyed and provide actionable steering for imposing steady encryption structures nowadays and making ready for destiny cryptographic challenges.

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