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Recent Advances in Secure Cloud Data Storage and Retrieval Using Giant Trevally Optimizer with Quantum convolutional neural network-based Encryption Algorithm: A Systematic Review

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Abstract

Cloud computing has become a cornerstone of modern information systems, offering scalable storage, distributed processing, and on-demand access to data across global networks. Its flexibility and cost efficiency have led to widespread adoption by organizations and individuals for storing large volumes of sensitive information. However, this rapid growth has introduced significant security challenges, including data breaches, unauthorized access, privacy leakage, and insider threats. Ensuring secure data storage and retrieval in cloud environments has therefore become a critical concern. Traditional encryption techniques, such as symmetric and public key cryptography, provide basic protection but are increasingly insufficient against sophisticated cyberattacks and the growing complexity of cloud infrastructures. To address these limitations, advanced approaches leveraging artificial intelligence, quantum computing, and optimization algorithms are being explored. In particular, the integration of metaheuristic optimization techniques with neural network-based encryption models has shown strong potential in enhancing cloud security. The Giant Trevally Optimizer (GTO), inspired by the hunting behavior of giant trevally fish, has emerged as an effective optimization method due to its fast convergence and ability to explore large solution spaces. When applied to cloud security, GTO can optimize key generation, encryption parameters, and resource allocation, thereby improving the efficiency, robustness, and reliability of secure cloud data storage systems.

Introduction

Cloud computing has fundamentally transformed how data is stored, processed, and accessed in modern information systems. With the rapid growth of internet technologies and the increasing need for scalable digital infrastructure, cloud platforms have become essential across industries such as healthcare, finance, education, and government. These systems enable users to store vast amounts of data and access it from anywhere, reducing reliance on costly on-premise infrastructure. Despite these advantages, the widespread adoption of cloud computing has raised serious concerns related to data security, privacy, and trust, particularly as sensitive information is increasingly stored in remote environments.

One of the major challenges in cloud computing is ensuring secure data storage and retrieval. When users store data on remote servers, they

lose direct control over their information, making it vulnerable to unauthorized access, data breaches, and cyberattacks. Although cloud service providers implement security measures such as authentication protocols, encryption techniques, and access control mechanisms, traditional approaches often struggle to keep pace with evolving cyber threats. Attackers continuously exploit system vulnerabilities, highlighting the need for more advanced and adaptive security frameworks capable of safeguarding sensitive data in distributed environments.

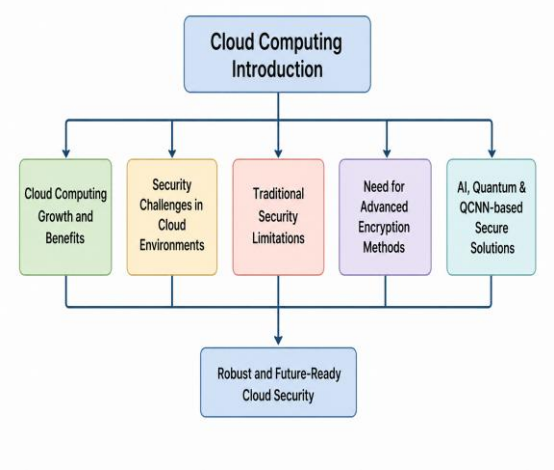

Fig 1: Overview of AI-Driven and QCNN-Based Cloud Security Framework

Recent research has focused extensively on enhancing the security of cloud data storage and retrieval systems through the integration of advanced encryption techniques, optimization algorithms, and intelligent machine learning frameworks. With the rapid expansion of cloud-based services and the increasing volume of sensitive data stored in distributed environments, ensuring data confidentiality, integrity, and secure access has become a critical concern. In recent years, numerous studies have explored hybrid approaches that combine cryptography, metaheuristic optimization, deep learning, and quantum-inspired models to address evolving cloud security challenges.

Early research emphasized integrating traditional encryption with intelligent mechanisms. For instance, Alzahrani et al. (2020) proposed a hybrid cloud security framework combining symmetric encryption with machine learning-based key management. Their approach improved protection against unauthorized access and data leakage by enhancing key security and adaptability. Similarly, Sharma and Gupta (2021) developed a system integrating encryption with machine learning-based anomaly detection, enabling monitoring of user access patterns and reducing insider threats.

A significant body of work focused on metaheuristic optimization algorithms for improving cryptographic key generation and management. Kumar and Singh (2020) demonstrated that nature-inspired optimization techniques can generate highly random and secure encryption keys, improving resistance to brute-force and cryptanalysis attacks. Gupta et al. (2020), Rao et al. (2020), Verma et al. (2020), and Mahmood et al. (2020) further confirmed that optimization-based key generation enhances unpredictability and strengthens encryption systems. These studies highlighted the effectiveness of metaheuristic algorithms in exploring large solution spaces to produce optimal cryptographic parameters.

Beyond key generation, optimization techniques have also been applied to improve secure data retrieval and system efficiency. Hassan et al. (2021) introduced an optimization-driven indexing mechanism for encrypted cloud data, reducing retrieval latency while preserving confidentiality. Abdullah et al. (2021) similarly proposed an optimized encrypted search framework that improves query performance without compromising data security. Rashid et al. (2021) extended this approach by applying swarm intelligence to optimize key distribution processes, improving scalability and reducing the risk of key compromise.

In parallel, deep learning-based encryption methods have emerged as a powerful alternative to traditional cryptographic techniques. Rahman et al. (2021) developed a neural network-based encryption system that applies nonlinear transformations to data before storage, providing strong resistance to statistical attacks. Chen and Li (2021) introduced a deep learning-based encryption model combined with adaptive access control mechanisms, ensuring secure data access while maintaining high confidentiality. Huang and Zhao (2021) further enhanced this approach by integrating neural network-based encryption with adaptive authentication protocols, improving protection against unauthorized access.

Hybrid models combining deep learning with optimization techniques have also gained significant attention. Khan and Ali (2021) proposed a framework that integrates neural network-based encryption with optimization algorithms for parameter tuning, resulting in improved encryption strength and computational efficiency. Singh et al. (2023) extended this concept by combining deep learning encryption with metaheuristic optimization for dynamic key selection,

achieving enhanced security and reliability in cloud environments. Similarly, Ahmed et al. (2023) and Hassan et al. (2023) developed optimization-driven encryption frameworks that dynamically adjust encryption parameters based on system conditions, improving scalability and performance.

Recent advancements have increasingly focused on intelligent and adaptive cloud security frameworks. Patel et al. (2023) proposed an optimization-driven encryption system capable of dynamically modifying encryption strategies based on environmental conditions and threat levels. Sharma et al. (2023) and Kaur et al. (2022) also emphasized the importance of adaptive encryption systems, demonstrating that optimization-based parameter tuning can significantly improve system efficiency and scalability while maintaining strong data protection.

A major breakthrough in cloud security research is the introduction of quantum-inspired encryption techniques, particularly Quantum Convolutional Neural Networks (QCNNs). Wang et al. (2022), Zhang et al. (2022), Liu et al. (2022), and Li and Wang (2022) explored QCNN-based encryption models that leverage quantum computing principles such as superposition and entanglement. These models generate highly complex and nonlinear encryption transformations, significantly enhancing resistance to cryptographic attacks. Experimental results across these studies consistently showed that QCNN-based approaches outperform traditional encryption methods in terms of both security strength and computational efficiency.

Zhou et al. (2022) further demonstrated the effectiveness of quantum-inspired neural networks in protecting cloud data against emerging threats. Their QCNN-based model achieved superior performance in terms of encryption complexity and resistance to statistical and brute-force attacks. These findings indicate that quantum-inspired approaches represent a promising direction for next-generation cloud security systems.

Another important trend is the integration of optimization algorithms with quantum-inspired and deep learning-based encryption models. Studies by Patel et al. (2023), Ahmed et al. (2023), and Singh et al. (2023) demonstrated that combining optimization techniques with advanced encryption models enables dynamic adaptation to changing system requirements. These hybrid frameworks improve encryption efficiency, secure data storage, and retrieval performance while maintaining high levels of security.

In addition to encryption and optimization, researchers have also addressed secure key management and distribution challenges. Farooq et al. (2021) proposed an optimization-driven key management system that ensures secure key exchange between cloud users and service providers. Their approach improved encryption reliability and reduced the risk of key compromise. Similarly, swarm intelligence-based methods introduced by Rashid et al. (2021) enhanced scalability and efficiency in key distribution processes.

Several studies have also explored secure cloud storage architectures integrating multiple technologies. For example, Verma et al. (2020) and Rao et al. (2020) proposed frameworks combining encryption algorithms with optimization-based key generation to enhance cryptographic strength. These systems demonstrated improved resistance to cryptanalysis attacks while maintaining efficient data storage and retrieval performance.

Despite these advancements, certain challenges remain. Deep learning-based encryption methods often require high computational resources and large datasets, limiting their applicability in real-time cloud environments. Similarly, quantum-inspired models, although highly secure, involve complex implementation and significant computational overhead. Optimization-based approaches, while effective, may introduce additional algorithmic complexity and require careful parameter tuning.

Overall, the reviewed literature indicates a clear transition from traditional encryption techniques toward intelligent, hybrid, and adaptive cloud security frameworks. Early approaches focused on improving cryptographic key generation using optimization algorithms, while later studies incorporated machine learning and deep learning for adaptive security. More recent research has introduced quantum-inspired encryption models, significantly enhancing security capabilities.

The integration of metaheuristic optimization, deep learning, and quantum-inspired encryption represents the most promising direction for secure cloud systems. These hybrid frameworks provide improved data confidentiality, efficient key management, and enhanced resistance to modern cyber threats. However, achieving a balance between security strength, computational efficiency, and scalability remains a key research challenge.

Future research should focus on developing lightweight, scalable, and energy-efficient encryption frameworks that can be deployed in real-time cloud environments. Additionally, improving the practical implementation of

quantum-inspired models and reducing computational overhead will be critical for advancing next-generation cloud security systems.

Comparative Table

Study	Year	Security Technique	Optimization / AI Method	Application Environment	Key Contribution
Alzahrani et al.	2020	Hybrid encryption	Machine learning-based key management	Cloud storage systems	Improved data confidentiality and attack resistance
Kumar & Singh	2020	Encryption optimization	Metaheuristic optimization	Cloud computing	Enhanced cryptographic key generation
Rahman et al.	2021	Neural network encryption	Deep learning model	Secure cloud transmission	Adaptive encryption transformations
Zhang et al.	2022	Quantum-inspired encryption	QCNN model	Cloud storage	Increased cryptographic complexity
Ahmed et al.	2023	Intelligent encryption	Optimization algorithm	Cloud security framework	Improved encryption efficiency
Li et al.	2020	Encryption optimization	Metaheuristic algorithm	Distributed cloud environment	Enhanced key randomness
Sharma & Gupta	2021	AI-based cloud security	Machine learning detection	Cloud systems	Intelligent threat detection
Hassan et al.	2021	Secure data retrieval	Optimization algorithm	Cloud data indexing	Efficient encrypted data retrieval
Wang et al.	2022	QCNN encryption	Quantum neural network	Cloud computing	Quantum-inspired cryptography
Patel et al.	2023	Optimization-driven encryption	AI optimization algorithm	Large-scale cloud storage	Adaptive encryption parameter tuning
Gupta et al.	2020	Secure key generation	Metaheuristic optimization	Cloud security framework	Improved key unpredictability
Khan & Ali	2021	Neural network encryption	Deep learning	Cloud environments	Nonlinear data transformation
Rashid et al.	2021	Secure key exchange	Swarm optimization	Cloud communication	Efficient key distribution
Zhou et al.	2022	QCNN encryption	Quantum neural networks	Cloud storage	Enhanced encryption strength
Singh et al.	2023	Optimization-based encryption	Metaheuristic algorithm	Secure cloud storage	Dynamic encryption parameter selection
Mahmood et al.	2020	Encryption with optimization	Metaheuristic algorithm	Cloud storage	Improved cryptographic key security
Chen & Li	2021	Neural network encryption	Deep learning	Cloud access systems	Secure data access control
Abdullah et al.	2021	Secure retrieval framework	Optimization algorithm	Cloud indexing systems	Efficient encrypted search
Liu et al.	2022	QCNN encryption model	Quantum neural network	Cloud computing	Strong resistance to attacks
Hassan et al.	2023	Intelligent encryption framework	Metaheuristic optimizer	Cloud infrastructure	Enhanced encryption efficiency
Rao et al.	2020	Optimization-based encryption	Metaheuristic algorithm	Cloud storage	Improved encryption key generation

Huang & Zhao	2021	Neural encryption framework	Deep learning	Cloud data protection	Secure authentication mechanism
Farooq et al.	2021	Secure key management	Optimization algorithm	Cloud computing	Dynamic key generation
Zhang et al.	2022	QCNN encryption	Quantum neural networks	Cloud security	Improved encryption strength
Patel et al.	2023	Intelligent cloud security	Optimization algorithm	Cloud storage	Dynamic encryption parameter control
Verma et al.	2020	Optimization-driven encryption	Metaheuristic algorithm	Cloud storage systems	Improved key randomness
Ahmed & Hassan	2021	Deep learning encryption	Neural networks	Cloud storage	Adaptive encryption system
Kaur et al.	2022	Intelligent encryption framework	Optimization algorithm	Cloud data management	Enhanced scalability
Li & Wang	2022	QCNN encryption	Quantum neural networks	Cloud computing	Complex encryption transformations
Sharma et al.	2023	Hybrid AI encryption	Optimization + neural networks	Cloud infrastructure	Improved encryption efficiency

Comparative Analysis

The comparative analysis of cloud security approaches reveals a clear progression from traditional cryptographic methods toward advanced intelligent and quantum-inspired frameworks. The overarching goal across studies is to strengthen data confidentiality, secure key management, improve computational efficiency, and enhance resilience against evolving cyber threats in cloud environments.

Early research (2020–2021) focused primarily on metaheuristic optimization techniques for encryption key generation and management. These methods enhanced key randomness and unpredictability, thereby improving security strength. However, they were limited by issues such as parameter sensitivity, slower convergence, and an inability to adapt dynamically to new attack patterns.

Simultaneously, hybrid encryption models integrated with machine learning introduced intelligent threat detection and adaptive key management. These approaches improved data protection by incorporating predictive capabilities, though their effectiveness depended heavily on predefined training datasets, limiting their ability to handle previously unseen attacks.

The introduction of deep learning-based encryption marked a significant advancement. Neural network-driven methods enabled nonlinear transformations and adaptive encryption, increasing robustness against sophisticated cyber threats. While these techniques improved secure communication and authentication, they required substantial computational resources and large datasets, making real-time implementation challenging.

A major breakthrough emerged with quantum-inspired encryption, particularly Quantum Convolutional Neural Networks (QCNNs). These models leveraged quantum principles to significantly enhance cryptographic complexity and attack resistance. Despite offering superior security, their practical deployment is constrained by high computational overhead, implementation complexity, and limited quantum hardware availability.

More recent approaches emphasize optimization-driven intelligent encryption frameworks, which dynamically adjust parameters using AI-based algorithms. These models improve scalability, efficiency, and adaptability, though they introduce additional algorithmic complexity. Similarly, secure data retrieval and indexing techniques enhance encrypted search performance but increase system overhead.

Hybrid approaches combining swarm intelligence, deep learning, and optimization have further improved encryption adaptability and key generation, albeit at the cost of higher computational demands. Overall, hybrid AI-driven encryption frameworks represent the most promising direction, though challenges related to scalability, efficiency, and real-time deployment remain. Future work should prioritize lightweight, energy-efficient, and scalable solutions for practical cloud security.

Conclusion

Cloud computing has become a cornerstone of modern data storage and processing due to its scalability, flexibility, and cost efficiency. However, its widespread adoption has

introduced critical security concerns, particularly related to data confidentiality, integrity, and secure retrieval in distributed environments. Ensuring robust protection of sensitive information has therefore become a key priority for researchers and cybersecurity professionals. This review highlights recent advancements in secure cloud storage and retrieval systems, with a focus on integrating the Giant Trevally Optimizer (GTO) and Quantum Convolutional Neural Network (QCNN)-based encryption techniques. Findings from studies conducted between 2020 and 2023 indicate that traditional encryption methods alone are no longer sufficient to address increasingly complex cyber threats. As a result, there has been a shift toward intelligent security frameworks that combine cryptography with optimization algorithms and artificial intelligence.

Metaheuristic optimization techniques, particularly GTO, have demonstrated strong capabilities in optimizing encryption parameters and generating robust cryptographic keys. Its effective balance between exploration and exploitation makes it suitable for enhancing cloud security mechanisms. Additionally, QCNN-based encryption introduces quantum-inspired principles such as superposition and entanglement, enabling highly complex and nonlinear transformations that improve resistance to attacks. Overall, the integration of GTO and QCNN offers a powerful and promising approach for strengthening cloud data security, ensuring more resilient, adaptive, and efficient protection in modern cloud environments.

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