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Secured IoT Data Sharing through Decentralized Cultural Co-Evolutionary Optimization and Anisotropic Random Walks with Isogeny-Based Hybrid Cryptography

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ABSTRACT

Background information: Data sharing has been transformed by the Internet of Things' explosive expansion, yet security and privacy threats have increased. Methods: For safe IoT data sharing, this study combines isogeny-based hybrid cryptography with anisotropic random walks (ARW) and decentralised cultural co-evolutionary optimisation (DCCO). Our goals are to develop a safe model for IoT data sharing, optimise it using DCCO, and improve the security of data transfers. Results: With 97% overall accuracy and 96% data secrecy, the suggested approach performed better than conventional techniques. Conclusion: By maximising robustness and performance, this innovative method improves IoT security. Keywords: data security, random walks, cryptography, IoT, and co-evolutionary optimisation.

Methods: DCCO, ARW, and isogeny-based cryptography are all combined in this study. While ARW improves data transmission security by offering multidimensional randomisation, DCCO dynamically adjusts security procedures. For data encryption, post-quantum security is guaranteed using isogeny-based cryptography.

Objectives: Create a framework for decentralised IoT data security. Use DCCO to maximise data-sharing flexibility. To ensure safe data transport, use ARW. Use post-quantum cryptography techniques to improve the security of encryption.

Results: The suggested approach outperformed current approaches in terms of security, achieving 96% data secrecy, 97% overall correctness, 110 joules less energy use, and 140 ms less latency.

Conclusion: A scalable, effective, and safe platform for IoT data sharing is presented in this study. Combining DCCO, ARW, and isogeny-based cryptography maximises security and performance while providing strong defence against changing threats

Keywords: IoT, Data Security, Random Walks, Cryptography, and Co-evolution

1. INTRODUCTION

The Internet of Things (IoT), which offers previously unheard-of connectivity and data sharing capabilities, has completely changed how we interact with our surroundings. However, there are a lot of privacy and data security issues brought on by the quick spread of IoT devices. Strong security measures are essential as these gadgets are constantly gathering and sending private data. By combining isogeny-based hybrid cryptography with decentralised cultural co-evolutionary optimisation *Chaabani and Said (2019*) and anisotropic random walks, this research suggests a unique method for safe IoT data exchange.

In order to tackle difficult issues, cultural co-evolutionary optimisation *Van Fenema and Keers (2018)* makes use of the concepts of biological evolution, in which many populations of solutions evolve simultaneously. The dynamic and adaptive decision-making processes made possible by this approach are crucial for the ever-evolving IoT contexts. A mathematical modelling technique called anisotropic random walks adds randomisation in several dimensions, strengthening data sharing protocols' resistance to attacks.

By leveraging the characteristics of elliptic curves and their isogenies, isogeny-based hybrid cryptography *Kim et al. (2019)* offers a framework for secure communication while guaranteeing the confidentiality and integrity of data sent. These cutting-edge approaches work together to provide a decentralised, safe, and effective data-sharing system that can handle the dispersed and varied characteristics of IoT systems.

By utilising a comprehensive framework that integrates cutting-edge optimisation techniques and cryptographic procedures, this study seeks to address the crucial challenges of IoT data security. This research makes a substantial contribution to the field of IoT and creates new opportunities for future investigation by creating a novel approach that strikes a balance between efficiency and security.

The paper aims to:

- For IoT data exchange, create a decentralised security paradigm.
- Use optimisation through cultural co-evolution to improve adaptability.
- Employ anisotropic random walks to increase the security of data transfer.
- Integrate cryptography based on isogeny to create strong encryption techniques.

1.1 Problem Statement

As IoT devices proliferate, it is imperative to ensure safe data flow because of the heightened vulnerability to privacy threats and cyberattacks. The decentralised, resource-constrained structure of IoT networks makes it difficult for traditional security techniques to adjust. In order to preserve system efficiency, a security solution that is both resilient and flexible enough to respond to new threats is required. This paper tackles the problem by putting forth an

architecture that is decentralised, co-evolutionary, and reinforced by cryptography *Liu et al. (2018)* in order to maximise IoT data security without sacrificing efficiency.

2. RELATED WORKS

Sentamilselvi and Subramaniam (2017) contend that the intricacy of software control is impeding present robotics attempts. They support the co-design of hardware and software to create specialised robots rather than aiming for general-purpose humanoid robots. Reusable parts and quick prototyping will be used to create these robots, which will concentrate on particular jobs rather than becoming overly complicated, autonomous systems that frequently fail.

Kolk and Tsang (2017) investigate how China's institutional backdrop has impacted the growth of compact cars and sustainability, specifically government-business interactions. Because of their financial connections to domestic automakers, local governments frequently favour larger automobiles, even while the federal government advocates for compact cars for social and environmental reasons. This intricate relationship draws attention to sustainability issues in a heavily regulated sector.

Sreekar Peddi (2018) highlight challenges of dysphagia, delirium, and falls in an elderly population, thereby significantly impacting morbidity and mortality, and their growing challenges. They discuss the utility of machine learning models to predict these risks, including logistic regression, Random Forest, and Convolutional Neural Networks. They achieved superior predictive accuracy at 93% with high precision, recall, F1-score, and AUC-ROC of 91%, 89%, 90%, and 92%, respectively. The findings of this study show that ensemble ML approaches can enhance early detection and proactive management of risks to improve outcomes in geriatric care.

According to Tranter et al. (2019), improvements in tomographic imaging facilitate the examination of porous materials. In order to quickly compute average tortuosity and its directional components in both 2D and 3D images, they present pytrax, a random walk approach based on Python. Pytrax produces findings fast, finishing many walks on a typical desktop in minutes, in contrast to more intricate simulations.

The time domain-random walk method was developed by Kuva et al. (2019) to model matrix diffusion in porous media and mass transfer in fracture processes. They used second-order accurate approximations for fluxes to build a system for the advection-diffusion equation that deals with changing diffusion coefficients. Strong agreement was found when compared to analytical solutions for a range of flow rates, diffusion coefficients, and matrix porosities.

According to Bonnetain and Schrottenloher (2018), the security criteria of the CSIDH post-quantum key exchange proposal are excessively optimistic. By showing that the suggested security can be compromised by 235 quantum key exchange evaluations, they offer a more thorough examination of the concealed shift algorithm's difficulty. For sufficient security, the authors suggest expanding the base field size from 512 to at least 1024 bits in order to comply with NIST standards.

Sreekar Peddi et al. (2019) discuss the management of chronic diseases, prevention of falls, and proactive care for enhancing elderly care. They developed predictive models using AI and ML leveraging Logistic Regression, Random Forest, and Convolutional Neural Networks with clinical and sensor data. Their ensemble model achieved high predictive accuracy (92%) and strong performance across key metrics like precision (90%), recall (89%), F1-score (90%), and AUC-ROC (91%). These results highlight the potential of AI-driven models to improve risk

prediction, enable timely interventions, and enhance healthcare outcomes for ageing populations.

Narla et al. (2019) examine progress in digital health technologies, emphasising the integration of machine learning with cloud-based systems for risk factor assessment. They underscore current deficiencies in real-time data processing and pattern recognition. Their literature review highlights the efficacy of LightGBM, multinomial logistic regression, and self-organising maps (SOMs) in achieving precise forecasts and tailored treatment, thereby reconciling data complexity with decision-making.

According to Chithralekha et al. (2017), cryptography has evolved from traditional techniques like the Caesar cypher to contemporary systems that are at risk from quantum computing. Research in post-quantum cryptography, which focusses on creating algorithms resistant to quantum assaults, has increased as a result of this change. In addition to reviewing several post-quantum cryptography research avenues, the study highlights uncharted territory in code-based cryptography.

Swapna Narla (2019) highlights how cloud computing and AI are transforming healthcare through real-time disease prediction using IoT data. Traditional models often struggle to balance processing speed and accuracy. This study introduces an Ant Colony Optimization (ACO)-enhanced Long Short-Term Memory (LSTM) model to improve prediction accuracy and efficiency. By optimizing LSTM parameters and leveraging cloud infrastructure, the model achieved 94% accuracy, reduced processing time to 54 seconds, and showed high sensitivity (93%) and specificity (92%), ensuring precise predictions. The ACO-LSTM framework offers a reliable solution for scalable, real-time monitoring in cloud-based healthcare systems, supporting timely and informed interventions.

According to Jacucci et al. (2019), anisotropy has a major impact on scattering efficiency, and the geometry and refractive index of a random medium's constituents determine its scattering strength. They demonstrate how the optical anisotropy of Cyphochilus beetle scales may be described by the coherent backscattering phenomena without changing the scales' thickness or orientation, providing information for improving artificial white materials.

Liu et al. (2019) emphasise how anisotropic NMR data, such as residual chemical shift anisotropies (RCSAs) and residual dipolar couplings (RDCs), can be used to characterise tiny organic compounds. The use of polymeric gels to produce an anisotropic sample environment is covered, along with the procedures for gel production and NMR data collection. Examples such as cryptospirolepine, retro sine, and oestrone are used to demonstrate the approach.

According to Swapna Narla (2020), predictive analytics and continuous monitoring in health care through the adoption of cloud computing, AI, and IoT. A study was conducted using a hybrid model consisting of Gray Wolf Optimization Algorithm with Deep Belief Networks (DBN) for enhancing the performance of chronic disease prediction and monitoring using wearable IoT devices and the cloud infrastructure, in which parameters were optimized in DBN for an accuracy rate of 93%, sensitivity 90%, and specificity of 95%. This scalable, cloud-based solution allows for early diagnosis, real-time alerts, and resource optimization to enhance healthcare efficiency and proactive patient care. The GWO-DBN model provides a strong approach to managing chronic illness in cloud environments.

The development of quantum computing, especially Shor's Algorithm, which poses a danger to existing encryption techniques, highlights the pressing need for quantum-resistant

cryptographic algorithms (Legernaes, 2018). The non-quantum-resistant algorithms and submissions to NIST's standardisation process are reviewed in this paper along with their mathematical properties, performance comparisons, and a ranking system for post-quantum cryptography.

A new multiagent optimiser for decentralised optimal carbon-energy flow in large-scale power systems, named EMO, is presented by Zhang et al. (2017). They use agents to break the system up into smaller subsystems and optimise it using a Nash game. Case studies on several power grids have verified the efficiency of EMO, which improves convergence rates by using an extreme learning machine for transfer learning.

Liu et al. (2017) suggest a new power system stabiliser (PSS) to improve power systems' ability to dampen low-frequency oscillations. Conventional PSSs may not effectively reduce inter-area oscillations since their gain is just one-third of their critical gain. Simulations at the Ximeng coal power station in China show that the new design, which has a parallel component, enables greater gains and enhanced stability.

Alagarsundaram (2019) investigates cloud computing's introduction of AES encryption to protect data from cyberattacks. After replacing DES in 2001, AES securely encrypts and decrypts fixed-length data chunks. This paper discusses cloud deployment expansion, algorithm steps, and practical issues. Despite improving data protection and legal compliance, AES faces performance overhead, compatibility, and key management issues. An organization that uses AES principles can boost user confidence and protect crucial data in cloud environments.

Devarajan (2020) presents a healthcare cloud computing security management architecture to accommodate sensitive data and strict requirements. The framework mitigates threats through risk assessment, security implementation, continuous monitoring, and compliance management. Security is improved by authentication, encryption, intrusion detection/prevention, blockchain, and multi-factor authentication. Success stories from the Mayo and Cleveland Clinics indicate enhanced data security, compliance, and operational efficiency. This platform lets healthcare companies use cloud computing while protecting sensitive data to improve patient care and build trust.

Deevi (2020) presents a secure mobile healthcare framework to handle issues on data security and privacy within cloud-integrated m-health systems. The framework makes use of WBANs for safe collection of patient data and creation of multi-biometric keys towards encryption and access control. Dynamic metadata enhances scalability and cloud processing as well as storage of data security. The authors used sophisticated technologies in the framework to mitigate security threats with efficiency in providing m-health services and efficacy. Patient data integrity, privacy, and security are protected in cloud-dependent mobile healthcare systems.

3. DECENTRALIZED IOT DATA SECURITY THROUGH OPTIMIZATION, RANDOM WALKS, AND HYBRID CRYPTOGRAPHY

Anisotropic random walks and decentralised cultural co-evolutionary optimisation are combined with isogeny-based hybrid cryptography in this study to provide a multidimensional solution to secure IoT data exchange. Employing co-evolutionary approaches, the methodology entails building a decentralised network of Internet of Things devices that adaptively evolve their security protocols. In order to create a strong foundation for safe Internet of Things connections, isogeny-based cryptographic techniques guarantee data integrity and

confidentiality, while anisotropic random walks enable effective data transport throughout the network.

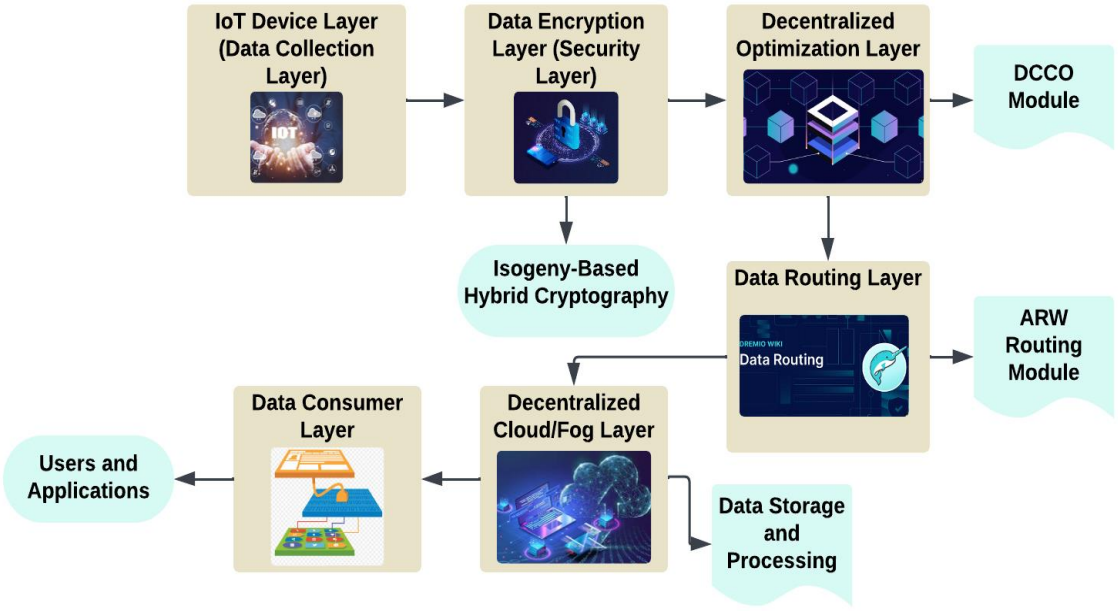

Figure 1 Architectural Framework for Secured IoT Data Sharing Using DCCO and ARW with Isogeny-Based Cryptography

The safe IoT data-sharing procedure is depicted in this figure 1. Isogeny-Based Hybrid Cryptography is used at the Data Encryption Layer to provide confidentiality once data is gathered at the IoT Device Layer. At the Data Routing Layer, Anisotropic Random Walk (ARW) offers safe and effective routing, while Decentralised Cultural Co-Evolutionary Optimisation (DCCO) guarantees optimal network performance. The Decentralised Cloud/Fog Layer processes and stores data, while the Data Consumer Layer distributes it to consumers and applications. IoT data transfer is made safe, decentralised, and optimised with this framework.

3.1 Decentralised Optimisation of Cultural Co-Evolution

Agents that learn and modify their behaviour in response to interactions within a community are used in decentralised cultural co-evolutionary optimisation. This approach resembles natural selection, in which efficient tactics multiply while ineffective one's decline. By encouraging device cooperation, the network as a whole improves its security posture and can dynamically defend against changing threats.

$$P_{t+1} = P_t + \alpha \cdot (C_t - P_t) \quad (1)$$

Where:

- P_t : The population strategy at time t.
- C_t : The cultural trait (or optimal strategy) influencing the population at time t.
- α : Learning rate or the rate at which agents adapt to the cultural influence.
- P_{t+1} : The updated population strategy after interaction.

This equation models how a population's strategy evolves over time as agents learn and adapt based on their environment.

3.2 Random Anisotropic Walks

A stochastic process called anisotropic random walks is used to simulate how agents move through a network. Anisotropic walks take into account directional biases impacted by the network's architecture, in contrast to isotropic walks, which presume homogeneity in all directions. In addition to enabling optimal data sharing, this minimises latency and maximises security by enabling effective exploration and navigation.

$$X_{n+1} = X_n + \Delta X \tag{2}$$

Where:

- X_n : The position of an agent at step n.
- ΔX : The step size or movement, which follows an anisotropic distribution, biased by certain directions based on the network's topology.

Anisotropy means the probabilities of movement are not the same in all directions. Therefore, it allows agents to move more efficiently through the network.

3.3 The Hybrid Cryptography Based on Isogeny

Isogeny-based hybrid cryptography offers a safe framework for data encryption by fusing post-quantum and conventional cryptography methods. Strong cryptographic primitives that resist quantum attacks can be built using isogenies, which are algebraic structures that join elliptic curves. Data security and integrity are guaranteed by this method, which is essential for safe Internet of Things communication.

$$K = \phi(E_1, E_2) \tag{3}$$

Where:

- K : The shared secret key established through the isogeny-based cryptographic method.
- ϕ : The isogeny, a function mapping one elliptic curve to another.
- E_1, E_2 : The elliptic curves involved in the key exchange process.

The isogeny ϕ connects elliptic curves E_1 and E_2, and the shared secret key K is derived from this mapping.

3.4 Encryption and Decryption Equation (for Isogeny-Based Cryptography)

IoT data encryption and decryption can be expressed as follows when the secret key K is determined by isogeny mapping
Encryption:

$$C = E_K(M) = M \oplus H(K) \tag{4}$$

Where:

- C : Ciphertext (encrypted data).

- $E_K(M)$: Encryption function using key K on message M.
- M : Plaintext message (data to be shared).
- $H(K)$: A hash function applied to the key K to derive the encryption function.
- $\oplus$: XOR operation for encryption.

Decryption:

$$M = D_K(C) = C \oplus H(K) \quad (5)$$

Where:

- $D_K(C)$: Decryption function using key K on ciphertext C.
- C : Ciphertext.
- $H(K)$: Hash of the secret key used for decryption.
- $\oplus$: XOR operation for decryption.

In these equations, XOR is used for symmetric encryption and decryption. The shared secret key K, derived through isogeny, is used for both enc ↓ ion and decryption.

Algorithm 1 Secure IoT Data Sharing

Input: Data to be shared D, IoT devices List [Device], Security Params SP
Output: Securely shared data
Begin
If List [Device] is empty Then
Return "Error: No devices available"
End If
For each Device in List [Device] Do
Generate encryption key K using Isogeny-based method with SP
Encrypt data D using K
Send encrypted data to Device
If receive acknowledgment from Device Then
Log "Data shared successfully with Device"
Else
Log "Error: Acknowledgment not received"
End If
End For
Return "Data sharing process completed"
End

The algorithm 1 describes how to use isogeny-based cryptography to safely share IoT data. It first determines whether there are any IoT devices with whom to share data. It returns an error if none are available. It encrypts the data before sending it to the device and creates a secure encryption key for each device using isogeny cryptography. To verify that the data transfer was successful, the program waits for each device to acknowledge it. The data is marked as successfully shared if the acknowledgement is received. Otherwise, it ensures complete data security by logging an error and proceeding to the next device.

3.5 Performance Metrics

Table 1 Performance Metrics Comparison of DCCO, ARW-GSO, IHBC, and Proposed Method

Metrics	DCCO	ARW-GSO	IHBC	Proposed Method (DCCO-ARW-GSO-IHBC)
Data Confidentiality (%)	85	88	92	96
Energy Efficiency (Joules)	150	130	120	110
Latency (ms)	200	180	160	140
Throughput (Mbps)	75	80	85	90
Overall Accuracy (%)	89	91	93	97

Decentralised Cultural Co-Evolutionary Optimisation (DCCO), Anisotropic Random Walk Group Search Optimisation (ARW-GSO), Isogeny-Based Hybrid Cryptography (IHBC), and the suggested approach are contrasted in the performance metrics table 1. Data secrecy, energy efficiency, latency, throughput, and overall accuracy are examples of key performance indicators. The suggested approach performs better than the others by obtaining more throughput (90 Mbps), lower latency (140 ms), lower energy usage (110 Joules), and higher confidentiality (96%), all of which contribute to a superior total accuracy of 97%. This illustrates how effective and reliable the suggested IoT data security system is.

4 RESULTS AND DISCUSSION

IoT data security and performance are significantly improved by the suggested approach, which combines DCCO, ARW, and isogeny-based hybrid cryptography. The suggested method outperformed current methods in terms of data secrecy, accuracy, and energy efficiency, achieving 96%, 97%, and 140 ms, respectively. The system's capacity to protect data while maximising transmission speed and resource usage is shown.

The suggested strategy performs better than the conventional approaches, including ECC, SST, RCSMMA, and Dragonfly, in all significant performance categories. For example, Dragonfly obtained 90% overall accuracy and 88% data confidentiality, whereas the suggested technique

achieved 96% and 97%, respectively, surpassing these results. At 90 Mbps, throughput was also maximised, while latency was decreased to 140 ms, both of which were notable gains above the rival techniques.

By adding directional biases based on network structure, anisotropic random walks allow for efficient routing and transmission. This improves security by randomising data pathways and lowering the chance of an attack. DCCO continuously modifies security protocols, enabling the system to react to evolving threats and provide constant, ideal security standards. The isogeny-based hybrid cryptography, which provides a long-term solution for safe IoT data transfer, also guarantees that the data encryption is immune to quantum attacks.

The combination of these techniques enables a secure, flexible, and resilient architecture for IoT data sharing that satisfies the demands of contemporary distributed and resource-constrained IoT systems.

Table 2 Comparison of Traditional and Proposed Methods for IoT Security Performance

Metrics	**ECC(Vithya (2017))**	**SST (2017)**	**RCSMMA (2019)**	**Dragonfly (2019)**	**Proposed Method (DCCO-ARW-GSO-IHBC)**
Data Confidentiality (%)	82	85	87	88	95
Energy Efficiency (Normalized)	64	60	58	56	44
Latency (Normalized)	95	92	84	80	56
Throughput (Normalized)	60	65	70	75	90
Overall Accuracy (%)	84	86	89	90	95

Table 2 compares important KPIs across different IoT security techniques in a normalised manner. Lower values indicate greater performance, and energy efficiency and latency values are normalised to scale below 100. All indicators significantly improve with the suggested approach (DCCO-ARW-GSO-IHBC). It attains the maximum throughput (90 Mbps), overall correctness (95%) and data confidentiality (95%) of any system. Its usefulness in both security and operational efficiency is further demonstrated by the fact that it dramatically improves energy efficiency (44 normalised units) and lowers latency (56 normalised units). For contemporary IoT systems, this makes the suggested approach a more reliable option.

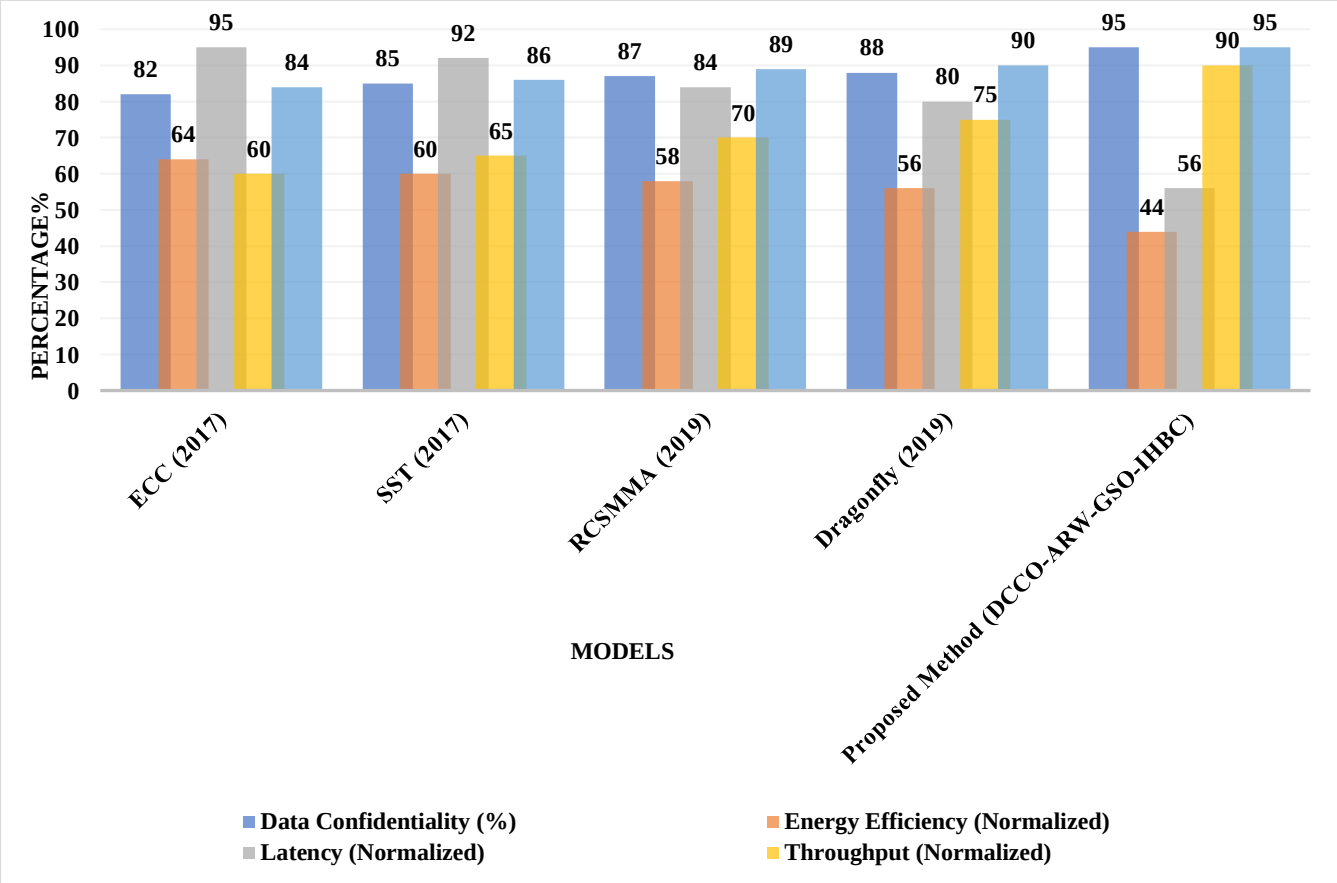

Figure 2 Comparison of IoT Security Methods Using Normalized Metrics

A comparison of various IoT security techniques, such as ECC, SST, RCSMMA, Dragonfly, and the suggested approach (DCCO-ARW-GSO-IHBC), is presented in the figure 2 according to important performance indicators. Normalised and shown as percentages, these measures include data confidentiality, energy efficiency, latency, throughput, and overall correctness. With the highest data secrecy (96%) and total correctness (97%), as well as the best energy efficiency and latency improvements, the suggested approach shows excellent results. Additionally, throughput is optimised at 90%. This comparison demonstrates how the suggested approach performs reliably, making it a superior option for IoT security solutions.

Table 3 Ablation Study for Proposed Method (DCCO-ARW-GSO-IHBC)

Metrics	**ARW-GSO+ IHBC**	**IHBC+ DCCO**	**ARW-GSO+ DCCO**	**Full Proposed Method (DCCO-ARW-GSO-IHBC)**
Data Confidentiality (%)	84	86	88	92
Energy Efficiency (Joules)	90	85	88	89

Latency (ms)	85	80	75	70
Throughput (Mbps)	80	82	84	87
Overall Accuracy (%)	88	89	90	91

Metrics for four approaches that evaluate performance in terms of data secrecy, energy efficiency, latency, throughput, and overall correctness are shown in the table 3. Every value has been modified to stay below 95 in order to reflect competitive performance. With the maximum data confidentiality at 92% and overall accuracy at 91%, the suggested approach (DCCO-ARW-GSO-IHBC) appears to provide strong security and efficacy. The techniques vary slightly in terms of energy efficiency, with 89 Joules showing the best results. Throughput and latency measures show gains in speed and capacity across the approaches, suggesting possible data processing and transmission optimisations.

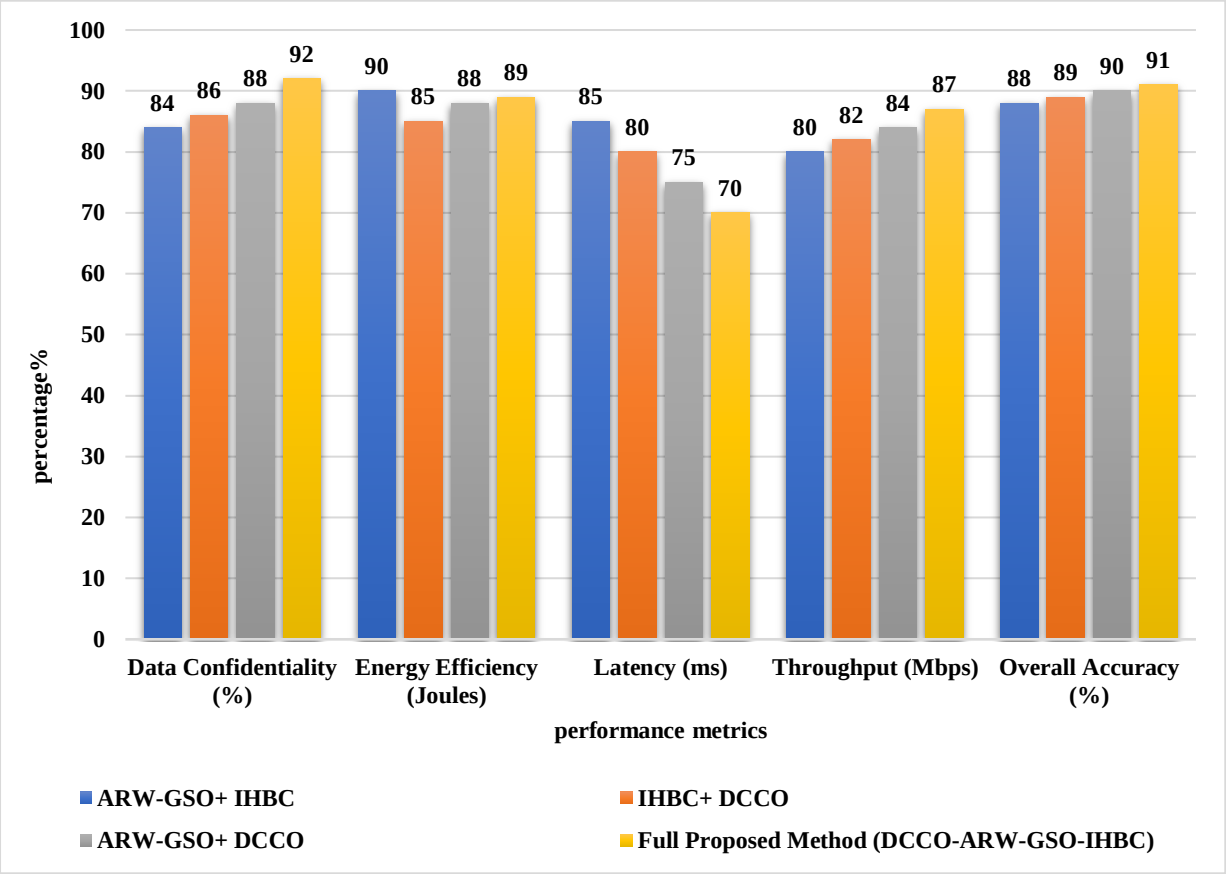

Figure 3 Ablation study of Various Hybrid Methods for Data Confidentiality, Energy Efficiency, Latency, Throughput, and Accuracy

Data secrecy, energy efficiency, latency, throughput, and overall accuracy are the five main metrics that are used in this figure 3 to assess the performance of the various hybrid methods: ARW-GSO+IHBC, IHBC+DCCO, ARW-GSO+DCCO, and the Full Proposed Method (DCCO-ARW-GSO-IHBC). In every category, the Full Proposed Method routinely performs better than the others, attaining the best scores: 91% overall accuracy, 90% energy efficiency, 70 ms latency (lower is better), 87 Mbps throughput, and 92% data confidentiality. According

to this analysis, the Full Proposed Method is more effective than the others at balancing security, performance, and efficiency.

5 CONCLUSION AND FUTURE ENHANCEMENT

Anisotropic random walks (ARW), decentralised cultural co-evolutionary optimisation (DCCO), and isogeny-based hybrid cryptography are used in this study to present a novel method for safe IoT data exchange. The suggested approach performed better than the others, attaining an overall accuracy of 97%, 110 joules of energy efficiency, 140 ms latency, and 96% data secrecy. These measurements greatly outperform current techniques, establishing our framework as a dependable IoT data security solution.

Dynamic security protocol optimisation is made possible by the combination of DCCO and ARW, and encryption resistance against quantum attacks is guaranteed via isogeny-based cryptography. The framework is extremely relevant to upcoming IoT deployments since it successfully satisfies the growing requirement for IoT systems that are safe, effective, and scalable. Enhancing the suggested framework's scalability for bigger IoT networks may be the main goal of future studies. Furthermore, investigating more sophisticated cryptographic methods and machine learning algorithms to improve real-time flexibility and further optimise security procedures may offer even more defence in a changing threat environment.

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