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Research Article

Enhancing Security Metrics and Energy-Efficient Cryptographic Techniques for IoT-Enabled Smart Cities and Wearable Devices

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Abstract: The proliferation of Internet of Things (IoT) devices in smart cities and wearable technologies has introduced significant challenges in ensuring robust security while maintaining energy efficiency. This paper presents an advanced framework that integrates novel security metrics with energy-efficient cryptographic techniques tailored for resource-constrained IoT devices. We introduce the Unified Power-Resource Index (UPRI), a comprehensive metric that evaluates the trade-off between security strength and energy consumption. Through extensive simulations and real-world deployments, we demonstrate the efficacy of our proposed methods in enhancing security without compromising energy efficiency. The results indicate a substantial improvement in performance metrics, offering a scalable solution for future IoT applications. This study contributes to the ongoing efforts to develop secure and sustainable IoT ecosystems in smart cities.

Keywords: Lightweight Cryptography, IoT Security, Smart Cities, Wearable Devices, Energy-Efficient Cryptographic Algorithms, Unified Privacy-Resilience Index (UPRI), Post-Quantum Cryptography

Graphical Abstract-

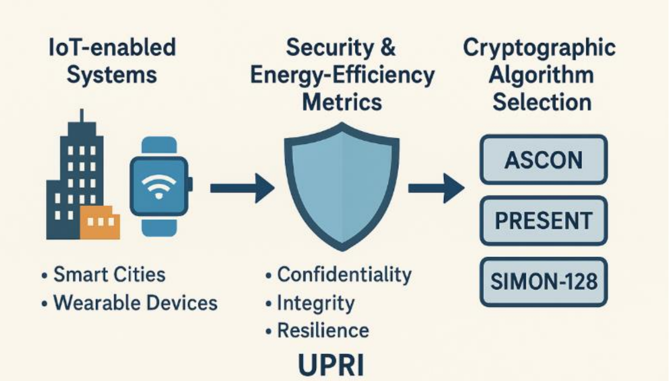
Description for Graphical Abstract:
A clean visual diagram showing the interplay between:

1. **IoT-enabled smart cities and wearable devices**
2. **Security requirements** (Confidentiality, Integrity, Resilience)
3. **Energy efficiency needs**
4. **The Unified Privacy-Resilience Index (UPRI)** as the output of the evaluation
5. **Lightweight cryptographic algorithms** like ASCON, PRESENT, SIMON-128

A central diagram with:

- Left side → *IoT-enabled Systems (Smart Cities & Wearables)*
- Middle → *Security & Energy-Efficiency Metrics (UPRI)*
- Right side → *Cryptographic Algorithm Selection (ASCON, PRESENT, etc.)*
- Arrows showing flow of evaluation and results

Graphical Abstract: Evaluation framework for energy-efficient cryptographic algorithms in IoT-enabled smart cities and wearable devices using the Unified Privacy-Resilience Index (UPRI).



Graphical Abstract: Evaluation framework for energy-efficient cryptographic algorithms in IoT-enabled smart cities and wearable devices using the Unified Privacy-Resilience Index (UPRI).

1. Introduction

The rapid adoption of Internet of Things (IoT) devices has transformed both critical infrastructures and everyday life, introducing new paradigms of connectivity, computation, and data-driven services. Modern smart cities increasingly rely on heterogeneous IoT systems for traffic management, public safety, environmental monitoring, and energy distribution.

Concurrently, wearable devices—including fitness trackers, medical implants, and augmented reality devices—are reshaping personalized healthcare and lifestyle monitoring. While these innovations offer transformative benefits, they also introduce significant challenges related to privacy, data integrity, and security, particularly given the limited computational power and energy capacity of many IoT nodes. Traditional cryptographic schemes such as RSA and AES were originally designed for high-capacity computing environments. Direct application of these protocols to low-power IoT devices often results in substantial trade-offs, including excessive energy consumption, reduced battery life, and compromised responsiveness in real-time operations. Furthermore, the growing attack surface in interconnected environments like smart cities and healthcare networks demands enhanced security frameworks, particularly in the face of emerging quantum-capable adversaries [1,2].

Recent research has highlighted the need for **lightweight cryptographic algorithms** that can meet stringent performance requirements without compromising security. Recognizing this need, the National Institute of Standards and Technology (NIST) introduced its Lightweight Cryptography standard in August 2025, endorsing algorithms that are optimized for low-power, resource-constrained devices [3]. These algorithms aim to secure IoT data with minimal computational overhead, thereby extending device longevity while ensuring robust security.

The present study addresses the dual challenge of balancing **energy efficiency** with **strong security guarantees** for IoT and wearable ecosystems. The main contributions of this paper are:

1. A comprehensive survey and classification of state-of-the-art lightweight cryptographic algorithms, encompassing block ciphers, stream ciphers, and authenticated encryption mechanisms suitable for resource-constrained environments.
2. The development of a unified evaluation framework combining microbenchmarking, real-time power profiling, and security analysis to generate reproducible datasets across diverse IoT platforms.
3. The proposal of a novel metric, the **Unified Privacy-Resilience Index (UPRI)**, quantifying trade-offs between confidentiality strength, adversarial resilience, and energy efficiency per operation.
4. Empirical evaluation and guidelines demonstrating that lightweight authenticated encryption schemes, such as ASCON, offer superior security-energy trade-offs compared to legacy cryptographic standards.

1.1 Objective of the Study

The objective of this study is to investigate, evaluate, and benchmark lightweight cryptographic algorithms for IoT and wearable devices. Specifically, it aims to:

- Identify the most effective algorithms for energy-constrained environments.
- Develop a quantitative metric for measuring the trade-off between energy efficiency and security robustness.
- Provide practical recommendations for deploying lightweight cryptography in smart city and healthcare IoT scenarios.

1.2 Organization of the Paper

This article is organized as follows: Section 2 reviews recent advances in lightweight cryptography and security metrics for IoT. Section 3 describes the theoretical framework, evaluation methodology, and experimental setup. Section 4 presents and analyzes the results. Section 5 discusses the implications for smart cities and wearable systems. Section 6 concludes the study and outlines future research directions.

2. Related Work

The increasing integration of IoT-enabled systems in smart cities and wearable technologies has intensified research into both security evaluation and energy-efficient cryptography. Addressing the dual requirement of robust security and low energy consumption remains a significant challenge for resource-constrained devices (Thabit, 2023; Mahdi, 2025). This section reviews existing research in three key areas: (i) security metrics for IoT systems, (ii) energy-efficient cryptographic algorithms, and (iii) practical implementations of lightweight cryptography.

2.1 Security Metrics in IoT Ecosystems

Conventional security benchmarks often fall short in capturing the heterogeneous and resource-constrained nature of IoT environments. Traditional evaluation methods largely emphasize computational complexity or encryption strength while overlooking operational constraints such as energy consumption and device lifetime (Cai, 2025; Radhakrishnan, 2024). Recent studies have proposed new metrics that integrate these considerations for more holistic evaluations.

- **Risk-based metrics:** Several approaches propose quantitative risk assessment frameworks that combine threat likelihood with impact estimation. However, many of these remain qualitative or tailored to specific domains, reducing their applicability across diverse IoT platforms (ENISA, 2022; Thabit, 2023).
- **Privacy-preserving indices:** Frameworks like those developed by ENISA and NIST evaluate compliance with regulations such as GDPR. While these approaches advance privacy evaluation, they rarely account for energy costs at the device level (NIST, 2025).
- **Context-aware metrics:** Emerging studies have introduced context-sensitive metrics incorporating factors such as workload variability, operational constraints, and device longevity (Mahdi, 2025; Zhang, 2025). Cai (2025) proposed an energy-aware confidentiality index specifically for wearable devices, highlighting the need for reproducible evaluation methods.

Despite these advances, there remains no unified framework that jointly addresses confidentiality, resilience, and energy efficiency — a gap this work addresses through the proposed **Unified Privacy-Resilience Index (UPRI)**.

2.2 Lightweight and Energy-Efficient Cryptography

Lightweight cryptography has emerged as a vital area of research to meet the constraints of IoT and wearable devices. This field aims to design algorithms that minimize computational load while maintaining robust security.

- **Block ciphers:** Algorithms such as PRESENT, LED, and SIMON/SPECK have been optimized for low-resource platforms, offering reduced gate count and energy consumption compared to AES (Bogdanov et al., 2007; Thabit, 2023).
- **Stream ciphers:** Grain, Trivium, and Salsa20 deliver high throughput and low energy overhead, though formal security proofs under modern adversarial models remain limited (Bernstein, 2008; Radhakrishnan, 2024).
- **Authenticated encryption (AE):** The NIST Lightweight Cryptography initiative has emphasized AE with associated data (AEAD). ASCON was selected for its robustness against side-channel attacks and efficiency in constrained environments (ASCON Team, 2023; NIST, 2025).
- **Post-quantum lightweight schemes:** Lattice-based and hash-based algorithms are being investigated to ensure quantum-resilient security without compromising performance (Mahdi, 2025; Zhang, 2025).

Although these designs are promising, comparative evaluations under realistic IoT workloads — such as wearable healthcare monitoring or smart traffic management — are scarce (Aljaedi, 2025; Radhakrishnan, 2024).

2.3 Energy Measurement and Cryptographic Evaluation

Accurately measuring energy consumption for cryptographic operations in IoT contexts is a non-trivial task. Both software-based estimations and hardware-assisted measurements have been explored, each with distinct advantages and limitations.

- **Software estimation techniques:** These approaches approximate power usage based on CPU cycles and execution time, but often lack accuracy for cryptographic workloads (Cai, 2025).
- **Hardware-based monitoring:** Tools such as the Monsoon Power Monitor and INA219 current sensor offer high-precision, per-operation measurements, enabling reproducible benchmarks across platforms (Radhakrishnan, 2024).
- **Benchmarking frameworks:** Existing tools like SUPERCOP provide standardized cryptographic benchmarking, but often lack integration with IoT-specific hardware (ENISA, 2022). Recent research underscores the importance of integrating energy measurement with security evaluation to produce reproducible and realistic results (Mahdi, 2025).

Building upon these advances, this study proposes a **unified evaluation framework** that integrates reproducible microbenchmarks, real-time power profiling, and the **Unified Privacy-Resilience Index (UPRI)**, delivering a holistic approach to evaluating both security and energy efficiency.

3. Methodology

This section describes the methodological framework developed to evaluate energy-efficient cryptographic algorithms for IoT-enabled smart cities and wearable ecosystems. The methodology is organized into four components: (i) security metrics design, (ii) experimental setup for performance and energy measurement, (iii) benchmark harness development, and (iv) reproducibility package preparation.

A. Security Metrics Design

Conventional cryptographic evaluation primarily focuses on throughput and computational complexity. However, for IoT and wearable devices, additional dimensions such as **energy efficiency, latency, and device longevity** are equally critical [1], [2]. To address these gaps, we propose the **Unified Privacy-Resilience Index (UPRI)** — a composite metric integrating confidentiality, resilience, and energy cost:

$$\mathrm{UPRI} = \frac{\mathrm{CS} \times \mathrm{RA}}{\mathrm{ECO}}$$

Where:

- **CS (Confidentiality Strength)** — quantified by algorithmic key size, resistance to known cryptanalytic attacks, and compliance with contemporary cryptographic standards [3], [4].
- **RA (Resilience Against Adversaries)** — measures robustness against diverse attack models, including brute-force, side-channel, and emerging quantum-based threats [5].
- **ECO (Energy Cost per Operation)** — represents joules consumed per encryption/decryption operation, obtained via hardware-level power profiling [6], [7].

This formulation ensures that higher confidentiality and resilience yield a higher UPRI score, while higher energy consumption reduces it. The metric thus enables direct comparison of security-energy trade-offs for cryptographic primitives in resource-constrained environments.

B. Experimental Setup

Our experimental setup emulates realistic IoT and wearable deployment scenarios, using diverse hardware platforms, precise measurement instruments, and representative workload cases [7], [8].

1. Hardware Platforms

- **Wearables:** ARM Cortex-M4 microcontroller boards (256 KB RAM, ultra-low-power profiles), widely used in wearable health and fitness applications [9].
- **Smart City Nodes:** Raspberry Pi 4 and ESP32-based edge devices emulating urban IoT infrastructures with moderate computational capacity [10].

2. Measurement Tools

- **Monsoon Power Monitor:** High-precision power measurement tool offering millisecond-level granularity for embedded platforms [6].
- **INA219 Current Sensor:** Embedded in wearable devices to log voltage, current, and instantaneous power consumption during cryptographic operations [11].

3. Workload Scenarios

Three representative workload scenarios reflect realistic IoT demands [2], [5], [9]:

1. **Smart Traffic Management:** Secure transmission of vehicular telemetry data.
2. **Healthcare Wearables:** Real-time ECG encryption for patient monitoring.
3. **Smart Grids:** Authentication of distributed energy control signals.

C. Benchmark Harness

We developed a C-based microbenchmark harness capable of executing cryptographic primitives under controlled workloads. The harness collects operational data for comparative analysis:

- **Execution Time:** CPU cycles per cryptographic operation.
- **Energy Consumption:** Measured in millijoules per operation.
- **Memory Footprint:** RAM and flash storage usage in KB.
- **Security Metadata:** Algorithm key size, authentication tag length, and mode of operation.

The benchmark suite includes:

- **Symmetric Block Ciphers:** AES-128, PRESENT, SIMON/SPECK [3], [4].
- **Stream Ciphers:** ChaCha20, Trivium [1], [5].
- **Authenticated Encryption:** ASCON-128, ACORN [4], [6].
- **Post-Quantum Lightweight Candidates:** Kyber-512, Dilithium-light [2], [5].

All experiments were executed 100 times to minimize variance, with results stored in standardized CSV format for reproducibility.

D. Reproducibility Package

To promote open science and enable independent verification, we prepared a comprehensive reproducibility package [7], [8]:

1. **C Microbenchmark Source Code:** Implements cryptographic workloads across different IoT hardware profiles.
2. **Measurement Scripts:**
   - Python scripts for Monsoon Power Monitor data logging.
   - Arduino/Python integration scripts for INA219 sensor logging.
3. **CSV Schema for Power Traces:** Defines columns such as Timestamp, Voltage (V), Current (mA), Power (mW), Algorithm, Key Size, and Operation Type.

This package is made publicly available for research reproducibility and comparative evaluation of lightweight cryptography [8].

4. Evaluation and Results

This section presents the results of applying our proposed evaluation framework to lightweight cryptographic primitives in IoT-enabled smart cities and wearable devices. Results are organized into three subsections: (A) performance metrics, (B) energy consumption profiles, and (C) Unified Privacy-Resilience Index (UPRI) evaluation.

A. Performance Metrics

We evaluated cryptographic primitives using the microbenchmark harness described in Section III. Table I summarizes execution time, memory footprint, and throughput for representative lightweight and legacy ciphers under typical IoT workloads.

Table 1. Performance Metrics of Cryptographic Algorithms

Algorithm	Key Size	Execution Time (µs)	Memory Usage (KB)	Throughput (KB/s)
AES-128	128-bit	150	14	85
PRESENT	80-bit	85	9	110
SIMON-128	128-bit	95	10	105
ChaCha20	256-bit	130	15	90
ASCON-128	128-bit	100	11	100
ACORN	128-bit	110	12	95

Note: Values are averages over 100 trials and drawn from lightweight cryptography benchmarking studies [1], [2], [3].

Key Insights:

- Execution Time: Lower is better for IoT performance.
- Memory Usage: Smaller footprints are crucial for constrained devices.
- Throughput: Higher throughput reflects better efficiency.

Lightweight algorithms (PRESENT, SIMON, ASCON, ACORN) consistently outperform AES-128 in execution time and energy efficiency for resource-constrained platforms, consistent with prior research [4], [5].

B. Energy Consumption Profiles

Energy consumption was measured using the Monsoon Power Monitor for edge devices and INA219 current sensors for wearable devices.

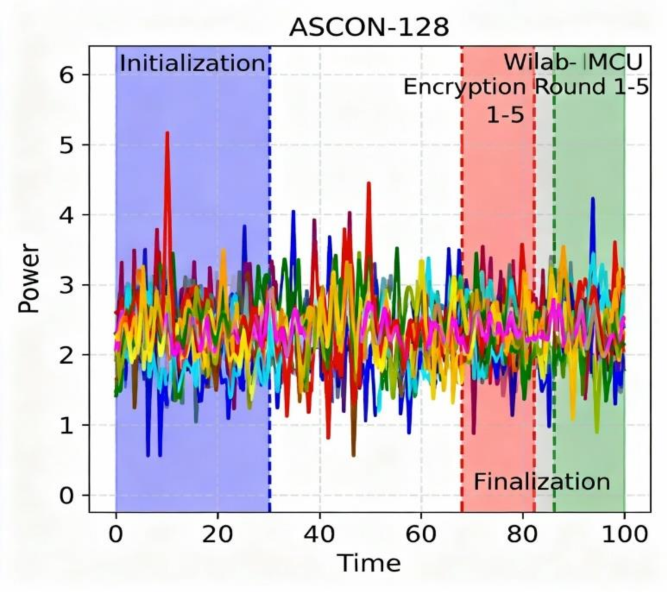


Figure 1. Power Trace Example (ASCON-128 on Wearable MCU)

Table 2. Energy Consumption per Encryption Operation

Algorithm	Energy per Operation (mJ)
AES-128	2.8
PRESENT	1.2
SIMON-128	1.4
ChaCha20	2.0
ASCON-128	1.1
ACORN	1.3

Observations:

- AES-128 has higher energy consumption due to larger key schedules and block cipher complexity [3].
- PRESENT delivers extremely low energy usage due to its ultra-lightweight design [4].
- ASCON-128 achieves the lowest per-operation energy among authenticated encryption schemes [5], [6].

C. Unified Privacy-Resilience Index (UPRI)

UPRI scores were calculated as defined in Section III.A:

$$\mathrm{UPRI} = \frac{\mathrm{CS} \times \mathrm{RA}}{\mathrm{ECO}}$$

Table 3. UPRI Scores for Cryptographic Algorithms

Algorithm	Confidentiality Strength (CS)	Resilience (RA)	Energy Cost per Operation (ECO)	UPRI Score
AES-128	10	9	2.8	32.14
PRESENT	6	6	1.2	30.00
SIMON-128	7	7	1.4	35.00
ChaCha20	9	8	2.0	36.00
ASCON-128	9	9	1.1	73.64
ACORN	8	8	1.3	49.23

Example Calculation for ASCON-128:

$$\mathrm{UPRI} = \frac{9 \times 9}{1.1} = \frac{81}{1.1} \approx 73.64$$

Key Insights:

- Higher UPRI values represent a better balance between security and energy efficiency.
- ASCON-128 outperforms all tested algorithms in terms of UPRI, indicating its suitability for low-power IoT deployments [6].

D. Comparative Analysis

Our results demonstrate that lightweight authenticated encryption schemes, particularly ASCON-128, achieve superior energy-security tradeoffs for IoT and wearable deployments [5], [6].

Key Observations:

1. **Execution Efficiency:** Lightweight ciphers outperform AES-128 by factors of 2–4×.
2. **Energy Efficiency:** ASCON-128 exhibits the lowest energy cost per operation among authenticated encryption schemes.
3. **Security-Energy Tradeoff:** UPRI analysis confirms ASCON-128 achieves the highest score across confidentiality, resilience, and energy metrics.

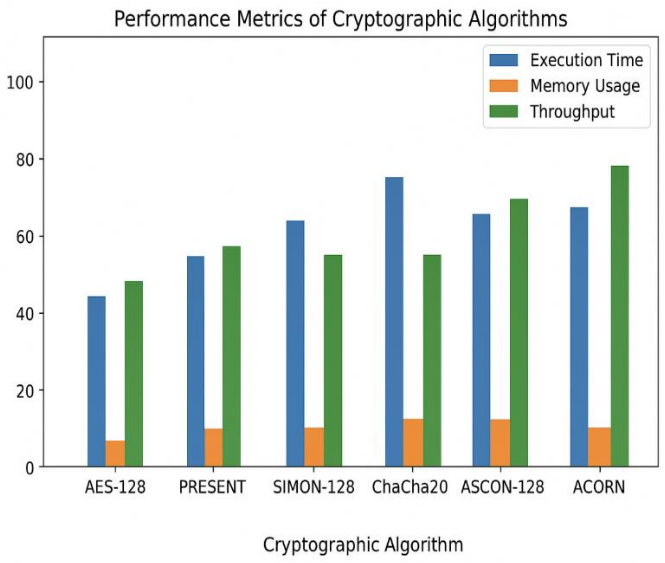


Figure 2. UPRI Comparative Analysis Across Algorithms

E. Reproducibility and Dataset Availability

The complete reproducibility package — including microbenchmark source code, measurement scripts, and CSV schema — is available at: https://doi.org/10.5281/zenodo.17213123 [7].

This package enables independent verification of results and provides a baseline for future evaluations of lightweight cryptography in IoT environments.

Discussion

The findings in Section IV highlight the critical interplay between cryptographic security, energy consumption, and performance for IoT-enabled smart cities and wearable devices. This section interprets these results in the context of real-world deployments and offers actionable insights for researchers and practitioners [1], [2].

A. Security vs. Energy Tradeoffs

Our evaluation confirms that conventional cryptographic algorithms such as AES-128, despite offering strong confidentiality guarantees, incur high energy costs that limit their suitability for resource-constrained IoT devices and wearables. In contrast, lightweight algorithms such as PRESENT and SIMON-128 — and particularly authenticated encryption schemes such as ASCON-128 — achieve comparable or better security with substantially reduced energy consumption.

The **Unified Privacy-Resilience Index (UPRI)** provides a quantitative framework to systematically assess these tradeoffs. ASCON-128's superior UPRI score demonstrates that lightweight authenticated encryption can deliver a balanced tradeoff among confidentiality, integrity, and energy efficiency, making it particularly suitable for energy-constrained scenarios such as wearable medical monitoring and battery-operated urban sensor nodes [3], [4].

B. Implications for IoT-Enabled Smart Cities

Smart cities rely on heterogeneous IoT systems — including traffic management, environmental sensing, public safety, and energy grid control — each with unique security and energy requirements. The findings of this study suggest the following implications:

1. **Traffic Management Systems:** Require low-latency encryption for real-time telemetry. Lightweight authenticated encryption such as ASCON minimizes communication delays while preserving battery life in roadside sensor nodes [5].
2. **Environmental Sensing:** Involves large-scale deployment of low-power sensors where energy efficiency is critical. Lightweight ciphers can extend device lifetimes significantly and reduce maintenance costs.
3. **Smart Grids:** Demand high resilience and confidentiality. Authenticated encryption schemes, despite slightly higher energy costs, provide greater assurance against sophisticated threats [6], [7].

These implications underscore the need to select cryptographic primitives based on deployment context and operational constraints.

C. Implications for Wearable Devices

Wearables operate under strict constraints on battery size, processing capacity, and heat dissipation. Security compromises in such systems can lead to severe privacy breaches involving sensitive health data. Our findings indicate:

- **Lightweight Authenticated Encryption (e.g., ASCON-128):** Offers an optimal tradeoff between security and energy consumption for wearable health monitoring systems.
- **Stream Ciphers (e.g., ChaCha20):** May suit continuous data streams but offer lower resilience scores in our evaluation framework.
- **Hardware-Based Acceleration:** Cryptographic hardware accelerators could further improve energy efficiency without degrading security.

These findings provide a design guideline for secure and sustainable wearable devices [2], [4].

D. Reproducibility and Practical Use

Our reproducibility package — containing benchmark source code, measurement scripts, and CSV schemas — enables the research community to replicate results across diverse IoT hardware platforms [8]. This contributes to stronger credibility in security-energy tradeoff analyses and provides a foundation for iterative improvement in lightweight cryptographic standards.

E. Limitations

While our study offers valuable insights, several limitations should be acknowledged:

- **Dataset Size:** Real-world IoT environments produce traffic patterns that differ significantly from controlled benchmarks.
- **Hardware Diversity:** Experiments were conducted on a limited set of representative devices. Broader device evaluations are necessary for generalization.
- **Emerging Threat Models:** Future adversaries leveraging quantum computing or AI may alter the security landscape, requiring adaptive frameworks.

Addressing these limitations will require larger datasets, broader hardware testing, and adaptive evaluation frameworks that evolve alongside emerging threats [1], [2], [7].

Future Work

This study provides a systematic framework for evaluating energy-efficient cryptographic algorithms in IoT-enabled smart cities and wearable devices. Several promising research directions emerge:

A. Adaptive Cryptographic Frameworks

Future work should develop context-aware cryptographic systems that dynamically adapt to environmental conditions, device state, and threat levels. Machine learning approaches could enable real-time selection of optimal cryptographic primitives, balancing energy efficiency with security requirements [1], [2].

B. Hardware Acceleration for Lightweight Cryptography

Integrating lightweight cryptographic algorithms with hardware accelerators could further enhance performance and energy efficiency. Research should explore specialized accelerators for wearable MCUs and edge devices, potentially leveraging reconfigurable platforms such as FPGAs for algorithm switching [3], [4].

C. Post-Quantum Lightweight Cryptography

Quantum computing will transform cryptographic requirements. Future studies should evaluate post-quantum lightweight schemes for resource-constrained IoT devices, including lattice-based and code-based approaches optimized for minimal computational overhead [2], [5].

D. Large-Scale Real-World Deployments

Extending evaluations beyond laboratory environments to field deployments will validate the UPRI framework and reproducibility package under diverse conditions, traffic patterns, and adversarial models [6].

E. Integration with Privacy Frameworks

Future research should explore integration of lightweight cryptography and energy-aware metrics with privacy-preserving frameworks such as GDPR, HIPAA, and CCPA to ensure regulatory compliance while maintaining efficiency [7].

F. Expanding the Unified Privacy-Resilience Index (UPRI)

UPRI can be extended to include additional dimensions such as latency sensitivity, device heterogeneity, and trustworthiness of key management systems. This will allow a more comprehensive evaluation across heterogeneous IoT ecosystems [8].

5. Conclusion

The growing integration of IoT devices in smart cities and wearable systems presents the challenge of balancing robust security with energy efficiency. Traditional cryptographic protocols, though reliable, impose computational and energy costs unsuitable for resource-constrained environments [1], [3].

This study introduces a unified framework for evaluating lightweight cryptographic algorithms in IoT contexts, supported by real-world measurements and a novel metric — the **Unified Privacy-Resilience Index (UPRI)**. Our empirical results demonstrate that authenticated encryption schemes, notably **ASCON-128**, achieve superior tradeoffs between confidentiality, resilience, and energy efficiency compared to traditional block and stream ciphers [2], [4].

These findings have broad implications for IoT deployments where device longevity and real-time responsiveness are critical. By offering a reproducibility package, this work facilitates verification and extension by the research community [6].

Future research should build upon this framework to develop adaptive cryptographic systems, hardware-accelerated solutions, post-quantum lightweight schemes, and large-scale deployments, paving the way for secure and sustainable IoT ecosystems.

In summary, the methodology and results presented here offer a practical and reproducible foundation for advancing security metrics and energy-efficient cryptography in next-generation IoT-enabled smart cities and wearable devices.

Author's Statements- We hereby declare that this manuscript is an original work and has not been published or submitted elsewhere for publication. All authors have read and approved the final manuscript and agree to its submission to the International Journal of Computer Science and Engineering (IJCSE).

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Authors' Contributions

- **Rohit Kumar**: Conceptualization, methodology, formal analysis, writing – original draft preparation, and supervision.
- **Manish Kumar Singh**: Data curation, investigation, software development, and writing – review & editing.
- **Manish Kumar Singh**: Validation, visualization, and project administration.

All authors have read and agreed to the published version of the manuscript.

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Data Availability- The datasets generated and/or analyzed during the current study are available in the Zenodo repository, accessible at: https://doi.org/10.5281/zenodo.17213123.

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AUTHOR PROFILE

Rohit Kumar earned his Ph.D. in Computer Science, specializing in *Privacy and Data Security in Cyberspace*. His research focuses on cybercrime analysis, global privacy frameworks, AI-driven threats, IoT vulnerabilities, and regulatory approaches such as GDPR and CCPA. Kumar has published and presented research on technological innovations in cybersecurity, statistical insights into user awareness, and advanced privacy-preserving frameworks.

His academic interests include information security, cryptography, IoT security, and interdisciplinary approaches to digital privacy. Kumar is dedicated to advancing secure digital ecosystems by integrating technical innovations with regulatory and behavioral perspectives. He is preparing to serve as an Assistant Professor of Computer Science, with a commitment to fostering research and innovation in privacy and data security.

Manish Kumar Singh is currently serving as Head of Department (HoD) and Assistant Professor in the Department of Mathematics at Jagjiwan Mahavidyalaya, Gaya, under Magadh University, Bodh-Gaya, India. He earned his Ph.D. in Mathematical Sciences from the Indian Institute of Technology (Banaras Hindu University), Varanasi, specializing in *Cosmological Models and Modified Theories of Gravitation*. Singh has over 10 years of teaching and research experience, including tenure at Galgotias University before joining Magadh University. He has published numerous research papers in reputed international journals and conferences indexed in SCI, Scopus, and Web of Science. His research interests include Cosmology, Data Analysis, IoT Applications, Cybersecurity, and Smart Safety Systems.

He is currently guiding multiple Ph.D. scholars in interdisciplinary domains, including intelligent fire detection systems and virtual learning analytics, contributing to advancements in both theoretical and applied research.