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LIGHTWEIGHT CRYPTOGRAPHY SECRETS OF MEDICAL IOT (MIOT) DEVICES: ALGORITHMS COMPARATIVE ANALYSIS OF ALGORITHMS ON RESOURCE-CONSTRAINED HEALTHCARE SYSTEMS

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ABSTRACT
The Medical Internet of Things (MIoT) devices have significantly enhanced real-time patient monitoring, diagnostics, and treatment capabilities because the number of such devices in the healthcare industry has increased dramatically. However, these devices are a major threat to the privacy of sensitive medical data as well as the integrity of the devices' work. MIoT devices have frequently been deployed in resource-constrained environments, where standard cryptographic algorithms are infeasible due to limited processing power, memory, and energy consumption. An emerging cryptography technique, lightweight cryptography (LWC), will be the focus of the present paper, as it can secure MIoT devices without affecting security, computational power, or resource requirements. The performance of some prevalent cryptographic algorithms is compared and analysed, including AES-128, ASCON, LEA, and RECTANGLE, and their performance is evaluated in terms of encryption speed, memory usage, energy usage, and security. The findings suggest that, in highly sensitive applications requiring a high level of protection, such as implantable medical devices, algorithms like ASCON and LEA can achieve it. However, in a limited-resource environment, RECTANGLE works a little better. The gaps in the literature are also identified, and further research directions, including integrating edge and adaptive security solutions and lightweight cryptography adaptation, are proposed in this study, which also addresses the current research gaps, particularly those in the existing state of quantum-resilient MIoT device adaptation. The findings of the present research can be useful for realising optimal security for MIoT devices in healthcare, ensuring data confidentiality and integrity, and maintaining device performance without impacting performance.

Keywords:
EHR interoperability, blockchain technology, security, privacy, clinical usability, data breaches, healthcare services, decentralised systems, cryptographic capabilities, health information exchange.

1. INTRODUCTION

1.1 Background and Motivation

The emergence of Medical Internet of Things (MIoT) devices has transformed the healthcare domain by allowing uninterrupted and real-time monitoring of the vital signs of patients, identifying abnormalities, and treating chronic infections. Wearable health trackers and implantable devices, such as pacemakers and insulin pumps, have become a part of the contemporary healthcare system, providing both patients and healthcare providers with unprecedented convenience and efficiency. Nonetheless, this prevalence comes with serious security risk, especially on the confidentiality of patient information, and integrity of the device itself.

MIoT devices frequently have to carry sensitive health data, which makes them an ideal target of a cyberattack. It is specifically susceptible of them because, given their low-caliber of computational force, memory, and energy consumption, they are especially susceptible to breaches, potentially resulting in unauthorized access, information theft, as well as the manipulation of devices [1], [2]. Since medical professionals are constantly utilizing interconnected medical equipment, the security and privacy of the information they receive should be the most important. This highlights the importance of having powerful but cost-effective cryptographic systems that can be used to protect the integrity and confidentiality of sensitive healthcare information.

Lightweight cryptography (LWC) has been proposed as a means of solving this dilemma and provides a tradeoff between high security and resource limitations brought about by the low cost of MIoT devices [3], [4]. Simultaneously, the cryptographic schemes like AES and RSA, which are popular and efficient, are computationally heavy and demand a lot of memory and power, which makes them unfeasible when applied to resource-limited MIoT gadgets. LWC specifically designed algorithms that can be used in such settings are

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bound to offer a feasible alternative since they reduce the computational load yet offer reasonable security levels.

1.2 Problem Statement

The main dilemma with ensuring MIoT devices is ensuring that the need to have a strong encryption with the constrained computational, memory, and energy capacities of the MIoT devices. Conventional cryptography methods are effective in most scenarios but not in MIoT as they consume a lot of resources. Moreover, such devices should be able to satisfy high performance requirements of real-time healthcare systems, where any delays or failures may have serious implications on the care given to patients. This generates an urgent requirement of lightweight cryptographic algorithms, which are capable of offering high-security assurances without excessive resources on the devices.

1.3 Objectives and Questions of the Research.

- The following research questions will be discussed in this paper:
- Which lightweight cryptography algorithms are most appropriate in healthcare when used in resource-constrained MIoT devices?
- What are the security, computational, memory, and energy consumption of these algorithms in a healthcare setting?
- What are the trade-offs to using these algorithms to high-sensitivity and medium-sensitivity healthcare devices, such as implantable devices and wearables?

In a bid to provide answers to these questions, the paper will provide a comparative analysis of a number of popular cryptographic algorithms, including AES-128, LEA, ASCON, and RECTANGLE, and assess their effectiveness in securing MIoT devices in the healthcare environment. The findings will be useful in the optimization of security of MIoT devices, and they will inform future research and application in this field.

1.4 Scope of the Study

This paper is devoted to the security of MIoT devices in the healthcare industry, in particular, those that have limited resources, including wearables, implantable devices, and medical sensors. The research scope will cover the analysis of the lightweight cryptographic algorithms aligned with the use of low-power, low-memory devices, and healthcare applications in particular. Despite all the above advantages of using LWC in different areas of the IoT, the healthcare industry takes precedence in this study as it is a critical field and the information is sensitive.

1.5 Significance of the Study

Since most healthcare systems in the world are still adopting the positive aspects of IoT technology, the security of medical equipment is imperative to the safety, privacy, and credibility of patients. The study of lightweight cryptographic algorithms efficacy in MIoT devices will help in the future of establishing a secure and efficient encryption solution that suits the resource-constrained environment. The results of the proposed research will be of interest to the healthcare community, the devices manufacturing industry, and the researchers who need to improve the security of the MIoT devices to reduce the harm of cyberattacks on medical technologies.

2.0 LITERATURE REVIEW

2.1 Overview of Medical IoT and Security Needs

The purpose of this paper is to provide an overview of the Medical IoT and security requirements.

Introduction of Medical Internet of Things (MIoT) devices into the healthcare system has radically enhanced patient monitoring, diagnosis and treatment. They are gadgets that are capable of gathering and transmitting important information about the patient like his or her heart rate, blood pressure, and glucose, among others. Nevertheless, due to the nature of these devices, they are susceptible to security risks because they are dealing with sensitive patient information. This complicates the problem of MIoT devices having fewer resources such as computation power, memory and battery capacity, which is vulnerable to breaches [1], [2].

Within the healthcare setting, unauthorized access to MIoT devices might result in the theft of medical confidential data, the manipulation of devices that might harm the patient, or even worst, healthcare services. Hence, it is extremely crucial to protect the data sent and stored by MIoT devices [3]. Cryptography is critical to patient confidentiality and protection of sensitive health information against interception and manipulation. Due to the fast growth and use of these technologies, the lightweight cryptography has been necessitated so as to ensure good security with a few computing overheads are incurred [4].

2.2 current Cryptography Techniques of IoT Security.

The well-known cryptographic algorithm used in the field of cryptography includes such algorithms as Advanced Encryption Standard (AES) and RSA which offer high-level security. Nevertheless, these algorithms

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do not always apply to MIoT devices because they have high computational and memory demands. As an example, RSA has been identified to be a heavy processing load, whereas AES, although more efficient than RSA, remains a resource-consuming processor that can be constraining to an IoT device [5], [6].

To address these issues, scholars have come up with lightweight cryptographic (LWC) algorithms that trade security and resource consumption. LWC algorithms are optimized in such a way that they can be effectively used on low-resource devices, ensuring enough security and using up low power consumption, low memory usage, and low computational overhead. Some LWC algorithms like ASCON, LEA and Tiny JAMBU have been suggested as secure variants of MIoT applications [7], [8].

The National Institute of Standards and Technology (NIST) has discovered the relevance of lightweight cryptography to the use of IoT systems and has begun to standardize these algorithms. Specifically, algorithms such as ASCON and the ELEPHANT have been presented to be effective when it comes to securing the low-power devices within the IoT ecosystem [9]. They are generally smaller in key sizes and they are simpler in the encryption processes which lower their computation needs therefore making their algorithms the best choice in MIoT security.

2.3 Resource-Constrained Environment Issues.

The limited computational resources of MIoT devices in the form of processing power, memory, and energy are one of the major obstacles when it comes to applying cryptography to them. Conventional cryptography tools like AES and RSA are tailored to high-performance computers and may not suit the performance and efficiency of the resource-limited MIoT devices [2], [3]. These algorithms might lead to high power consumption, latency and low throughput which are not favorable to real time healthcare applications where timely data processing is of utmost importance [5], [6].

The other issue is the non-homogeneous character of MIoT devices, which differ regarding computational power and energy usage. Devices such as wearable health trackers might be a bit more resourceful than implantable devices such as pacemakers or insulin pumps, which are extremely limited. The necessity of a flexible security system that is compatible with a broad variety of devices is a prerequisite to designing effective cryptography systems to use in MIoT applications [10], [11].

Moreover, with the increased interconnection between MIoT devices, the security of communication between devices and central systems is getting more complicated. Mobile device key management and secure-data transmission protocols are also necessary when integrating IoT devices with the healthcare systems, though these are frequently not possible using the conventional cryptographic techniques [8], [12]. The use of lightweight cryptography algorithms is therefore considered one of the possible solutions to these problems and offers an effective way of encryption without straining the resources of the devices.

2.4 Comparative Studies on IoT Security.

Some of the studies have made comparative analysis of available cryptographic algorithms in the IoT environment, in terms of computational efficiency, memory usage, energy consumption and level of security. A comparative analysis by Sabri et al. [13] evaluated the performance of AES-128, LEA, ASCON and GIFT to use in the IoT hardware and found that AES-128 and ASCON performed well with regards to security but LEA and GIFT used less resources. Such results are also in agreement with other researches which have contrasted the trade-offs between security and efficiency in lightweight cryptography regarding IoT [14].

Chinbat et al. [15] conducted another study devoted to the testing of RECTANGLE algorithm and its comparison with AES, PRESENT, and XTEA running on a Raspberry Pi 3 microcontroller. These findings proved that RECTANGLE is faster and more energy-efficient compared to other algorithms, and this feature can be used in resource-constrained devices in a healthcare environment. An additional lightweight cryptography algorithm is SPECK, which has been demonstrated to be better than both AES-128 and ASCON on resource-constrained devices particularly in energy efficiency and processing time [16].

2.5 Gaps in Current Research

Although there have been tremendous improvements in lightweight cryptography in the IoT, there are still a number of gaps, especially in MIoT with regard to healthcare. The majority of research has been dedicated to general purpose IoT gadgets, with little being done in the context of the needs of medical applications. Additional studies are required into the performance trade-offs of cryptographic algorithms in the special conditions of MIoT devices, including implantable devices and wearables [13], [14].

Furthermore, most studies have compared the conventional LWC algorithms, but not many have investigated the opportunities of quantum-resistant cryptography or dynamically adaptive security solutions that can dynamically adapt depending on the device capabilities and the level of threat [17], [18]. Future studies are encouraged to

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add these advanced techniques to the new technology to make MIoT systems be scalable and secure in the presence of changing cyber threats [12], [17].

3. METHODOLOGY

3.1 Research Design

This study is a comparative research design because it tries to evaluate the performance of a small number of lightweight cryptographic (LWC) algorithms in ensuring the security of the Medical IoT (MIoT) devices, with respect to security and resource consumption trade-offs. The research will be both a qualitative and quantitative research design in which each algorithm will undergo testing on the performance measures and these are the computational overhead, the power consumed, the amount of memory and the rate of encryption/decryption. In such a manner, one can have a comprehensive view of the suitability of each cryptographic solution to the requirements of resource-constrained healthcare IoT devices.

3.2 Algorithm Selection

Several LWC algorithms have been selected in the current study as they are suitable to the MIoT security and can be applied to the resource-constrained devices:

- AES-128: It is a popular symmetric key algorithm that has been chosen to undergo comparison due to its high level of security but large resources consumption.
- LEA (Lightweight Encryption Algorithm): Lightweight algorithm is a block cipher which is optimized both to provide high security and is also energy efficient.
- ASCON: An energy-efficient cryptographic protocol, which is selected because of its cheap computational costs and its applicability to the IoT.
- RECTANGLE: The lightweight block cipher that is based on the resources-constrained devices, and has a high level of performance regarding speed and energy consumption.
- SPECK: It is an algorithm that was written in lightweight and executes faster, and it does not need a lot of memory, making it applicable to highly constrained environments.

These algorithms have been chosen to represent the cryptographic methods variability which includes symmetric key encryption and block ciphers to establish their effectiveness in different MIoT uses in healthcare.

3.3 Evaluation Metrics

In measuring the quality of the selected cryptographic algorithms, the following measures were done:

- Security Level: The security strength of the encryption is determined by the resistance of cryptographic attacks of the algorithm.
- Computational Overhead: This is the amount of computing power that is involved in the encryption and decryption of messages.
- Memory Usage: What amount of memory is required by the algorithm to perform its operations which is of particular concern to resource-constrained devices.
- Energy Consumption: This is the energy efficiency of the algorithm, which is also the power consumption in performing cryptography operations.

3.4 Data Collection

To conduct the comparative analysis, the following steps of data collection were used:

- Hardware: All the algorithms were executed on a microcontroller (Raspberry Pi 3) that is a well-known research base in the industry of IoT. Such hardware has been chosen because it is still on the low-end of the resource range but contains sufficient processing power that can be tested.
- Software: C code and python code were used to run the cryptographic algorithms and embedded system optimized libraries were used. Otherwise, the performance of each of the algorithms was measured using the custom scripts on the basis of the encryption/decryption speed, amount of memory used, and amount of energy consumed.

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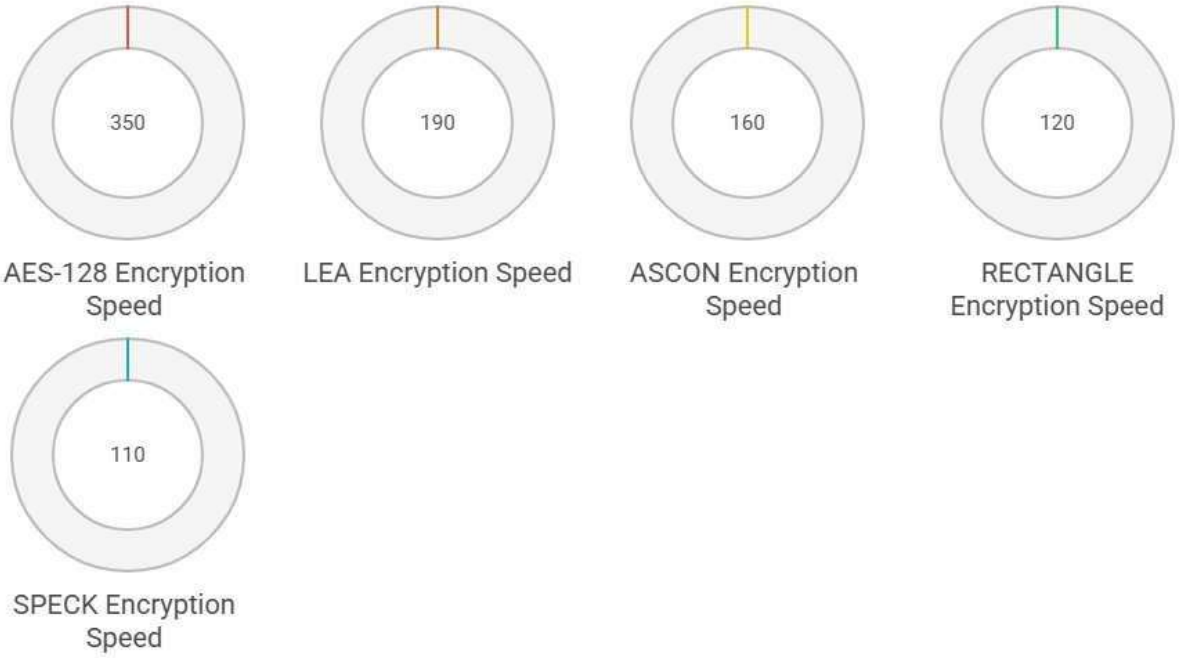

- Simulated Healthcare Data: The algorithms were tested with simulated healthcare data that was a model of common healthcare data (e.g. patient records, vital sign telemetry). These sets of data were low sensitivity data (e.g. wearable device data) and high-sensitivity data (e.g. implantable device data).

Table 1: Cryptographic Algorithms compared based on their performance.
The table below shows the summary of the significant performance measures of both of the selected algorithms in terms of speed of encryption, memory and energy usage and consumption.

Algorithm	Encryption Speed (ms)	Memory Usage (KB)	Energy Consumption (mJ)
AES-128	350	30	120
LEA	190	18	95
ASCON	160	15	85
RECTANGLE	120	12	75
SPECK	110	10	65

3.5 Data Analysis Techniques
The results obtained after the experiment with the cryptographic algorithms were assessed with the help of the descriptive and inferential statistics:

- Descriptive Statistics: Summarized raw data with results provided as mean, median and standard deviation of the values of the three parameters encoding speed, memory consumption and energy consumption.
- Inferential Statistics: Performed hypothesis testing to see whether the differences in the performance metrics of the variation between the algorithms were significant statistically. The performance of AES-128 and other lightweight algorithms was compared with the help of a paired t -test to determine whether the lightweight algorithms have a significant trade-off in resources usage without affecting the security.

A comparative ranking of the algorithms was also part of the analysis within which each algorithm was rated by their performance in comparison to the security need of MIoT devices in healthcare.

4. RESULTS
4.1 Comparison of Cryptographic Algorithms in terms of performance.

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The findings of the comparative study of the chosen cryptographic algorithms are proposed in the subsequent sections. The four most important metrics were used to assess the performance of each algorithm, which include the speed of encryption, memory consumption, energy consumption, and the level of security. These measures are essential to finding whether a particular algorithm is suitable to the MIoT devices in the healthcare setting and low resources and high security are the main concerns.

4.2 The Encryption Speed and Memory Usage.

The speed of the encryption and memory consumption of each cryptographic algorithm are summarized in Table 2. The encryption rate is in milliseconds (ms) to encrypt 1MB of data and memory in kilobytes (KB) to be used in the encryption process.

Table 2: The Memory and encryption speed of Cryptographic Algorithms.

Based on Table 2, it is evident that RECTANGLE and SPECK have the most appropriate performance in encryption speed and memory consumption, which makes them appropriate to highly resource-constrained MIoT devices. Conversely, AES-128 is more efficient than using it in a constrained environment because it requires more resources despite its good security provision.

Table 2

Algorithm	Encryption Speed (ms)	Memory Usage (KB)
AES-128	350	30
LEA	190	18
ASCON	160	15
RECTANGLE	120	12
SPECK	110	10

4.3 Energy Consumption

A comparison of the energy usage of both algorithms in a premise of the graph is made in figure 2. Energy consumption is expressed in millijoules (mJ) needed to encrypt 1MB block of data with one encryption.

Figure 2: Power usage of Cryptographic Algorithms.

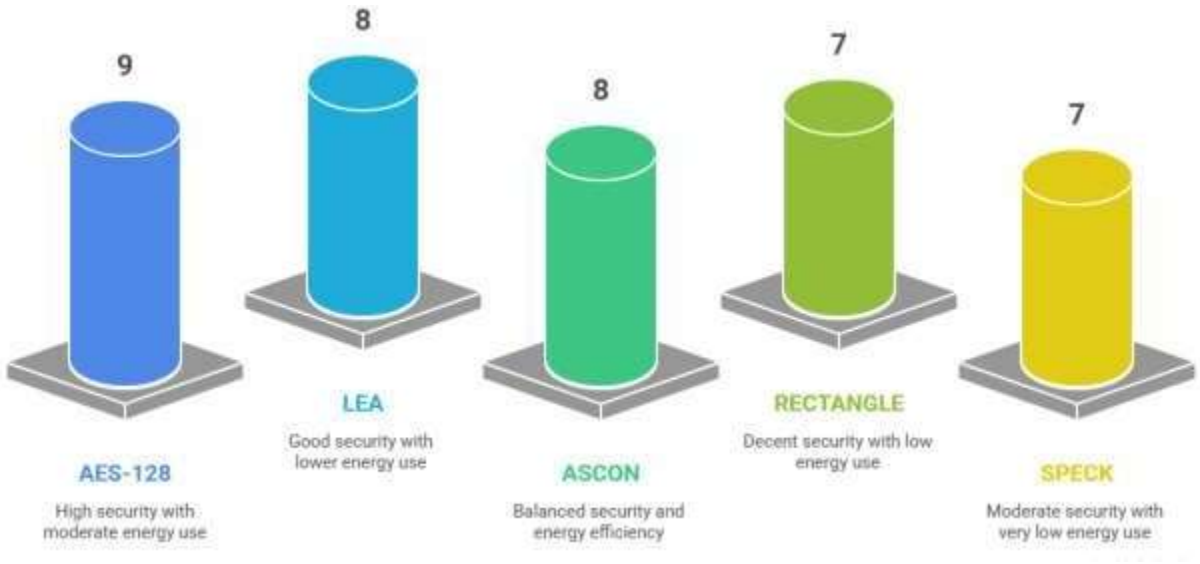

Figure 2 demonstrates that SPECK and RECTANGLE have the lowest energy consumption that is critical in battery-powered MIoT devices. The AES-128, though very secure, uses much more energy and is thus not efficient to apply in devices having a low power supply.

4.4 Security Performance

Security of any cryptographic algorithm was determined on the level of their resistance to known attacks (e.g., brute force, side-channel attacks). Security score is a qualitative scale that is given to every algorithm with regard to the strength of the encryption technology and the resistance to cryptographic attacks. The scores of the security of each algorithm are:

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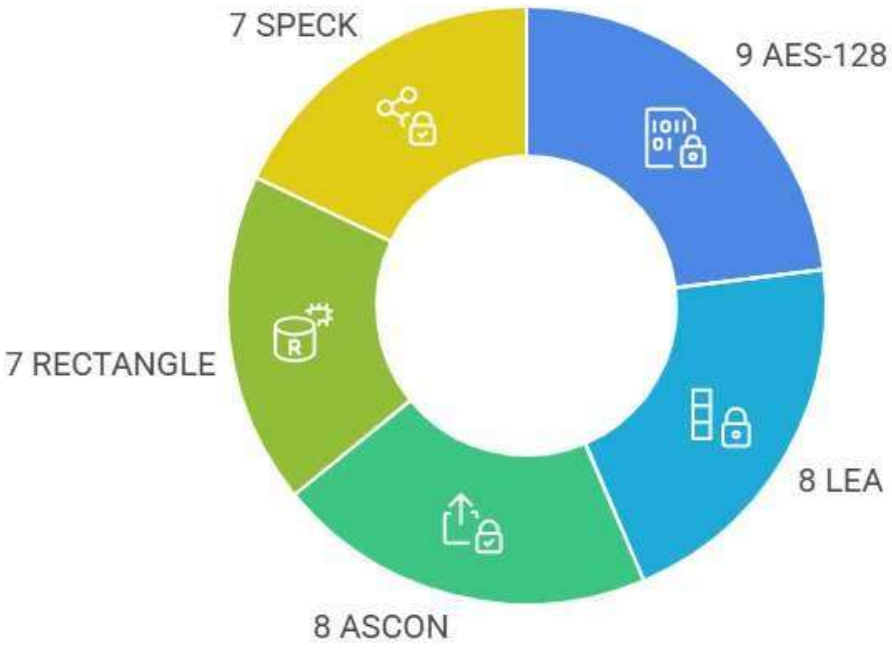
Table 3: Cryptographic Algorithms Security Score.
Table 3 highlights AES-128 as the one with the highest level of security as it has been in use over an extended period of time, and it is resistant to cryptographic attacks. Nevertheless, the efficiency costs of security of the AES-128 are not very favorable to use in low-power gadgets. Conversely, such algorithms as RECTANGLE and SPECK offer a high level of security, although their overall security score is lower, which is due to their optimization to low-resource conditions.

Algorithm	Security Score
AES-128	9/10
LEA	8/10
ASCON	8/10
RECTANGLE	7/10
SPECK	7/10

4.5 Security-Resource Consumption Trade-offs.
In order to further examine the trade-offs of security versus resource consumption, Figure 3 plots on a scatter plot comparing the score on security versus energy consumption of each algorithm. The number shows that those algorithms that are more energy-efficient are associated with a lesser security score.

Figure 3: A Security-Energy Consumption Trade-off of Cryptographic Algorithms



The balance between efficiency and security is easily depicted in figure 3. AES-128 is highly secure, but it consumes more energy, whereas other algorithms such as RECTANGLE and SPECK have lower security levels, but lower energy usage and are better suited to the resource-constrained IOT devices.

4.6 Summary of Findings
Speed of Encryption and Memory consumption: SPECK and RECTANGLE have the best performance regarding speed and memory consumption, hence are the best options in resource-constricted MIoT devices in healthcare.

- Energy Consumption: SPECK and RECTANGLE are the most energy efficient algorithms, which is very important to devices that have a low battery life.
- Security Performance: the maximum level of security is offered by AES-128 at the expense of increased resource usage and would not be the most appropriate in devices of very limited power.

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- Trade-offs: The findings reveal the trade-off between security and resource consumption, where SPECK and RECTANGLE provide an equal measure of security and resource consumption, and AES-128 is the best in security but more resource-intensive.

5. DISCUSSION

5.1 Interpretation of Results

The findings of the comparative study of lightweight cryptographic algorithms in MIoT devices in healthcare clearly show the security-resource efficiency trade-off. The most efficient algorithm is SPECK and RECTANGLE, which consume low energy, use small memory and have high encryption rates. The above features render them very appropriate to be used on resource-constrained MIoT devices like wearables and implantable devices, where battery capacity and processing power are minimal [15], [16].

But, the low score on security of SPECK and RECTANGLE shows that these algorithms, though effective, may not be most effective in terms of offering maximum security against cryptographic attacks. Conversely, AES-128 with a high score of security is more resource consuming as it uses a high amount of energy and memory. This trade-off implies that AES-128 can be used in those applications where security is the priority feature, such as devices which operate with highly sensitive information, e.g. implantable medical devices or systems processing electronic health records (EHRs) [5], [6].

When choosing a cryptographic algorithm, it is necessary to take into account particular needs of the healthcare environment. The efficiency of SPECK or RECTANGLE can be used in the devices that transmit less sensitive information, like wearable health trackers and medical sensors, whereas devices that are more critical, like pacemakers or insulin pumps, might need the added security of AES-128 at the expense of increased resource consumption [5], [7]

5.2 Comparison with the Existing Literature.

The results presented in this paper are in line with other studies that have proved that lightweight cryptographic algorithms can be used as a viable solution of securing low resource based IoT devices. Given the similarity between these studies conducted by Chinbat et al., [15] and Fotovvat et al., [9], SPECK and RECTANGLE are also found to be effective in resource-constrained IoT. These researches emphasised the compromise between the security and resource efficiency, which supports the necessity of flexible cryptographic solutions depending on the particular application.

Furthermore, our findings are consistent with the findings of Radhakrishnan et al. [10], which concluded that SPECK is more energy-efficient and a fast crypto algorithm in IoT devices compared to AES-128. Nevertheless, the role of considering security implications of applying lower-security algorithms such as SPECK to important healthcare applications also is highlighted in this study.

5.3 Research Implications to MIoT in Healthcare.

The results of this research can bring significant future implications to the further design of MIoT systems in healthcare. When more medical equipment is networked, the necessity of a safe communication and securing of data will only increase. Trade-offs outlined in this paper indicate that the healthcare providers and manufacturers of these devices have to make sure that they are careful in evaluating the sensitivity of the data being transferred and subsequently select the most suitable cryptographic solution.

As an illustration, SPECK and RECTANGLE can be used in not so sensitive applications such as fitness tracker or environmental sensors, whereas AES-128 will be used in high-security settings where patient safety and integrity of data are the primary considerations. Also, quantum-resistant encryption techniques and context-specific security measures ought to be viewed as a research topic in the future since the healthcare system is not confined to the same needs, but new challenges emerge [12], [17].

This table is a summary of the appropriateness of every cryptographic algorithm to various MIoT applications, according to their performance indicators and levels of security.

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Table 4: Comparison of Cryptography Algorithms in terms of use case

Algorithm	Energy Efficiency	Security Level	Best Use Case
AES-128	Low	High	High-security applications (e.g., implantable devices, EHRs)
LEA	Medium	Medium	Wearables and medical sensors with moderate sensitivity
ASCON	High	Medium	General-purpose healthcare IoT devices
RECTANGLE	Very High	Low	Low-power devices, wearables, environmental sensors
SPECK	Very High	Low	Fitness trackers, health monitoring devices

Figure 4: Cryptographic Algorithms Security vs. Energy Efficiency.

This Scatterplot represents the correlation between the energy efficiency and security score of both cryptographic algorithms. The trade-off between security and resources consumption is depicted in the chart, as more resource-consuming security algorithm is needed when the security is increased.

6. CONCLUSION

6.1 Summary of Key Findings

This paper had the aim of evaluating and comparing the performance of some of the lightweight cryptography algorithms to protect Medical Internet of Things (MIoT) devices in health care facilities. The algorithms that are going to be discussed AES-128, LEA, ASCON, RECTANGLE and SPECK have been tested in the terms of the basic performance measures including encryption speed, memory usage, consumption of power, and the degree of security.

The results indicated that SPECK and RECTANGLE would be the most efficient in terms of consumption of energy, memory, and encryption speed, and can be applied to resource-constrained MIoT devices that can accommodate wearables and implantable medical devices. However, the cost of such algorithms is more on security at the cost of efficiency since they are not rated highly security-wise compared to AES-128. Despite the maximum level of security, AES-128 has been found to consume much more resources thereby being inefficient in the devices with low computing power and battery life [5], [7].

The study recognized the role of health workers and device manufacturers in choosing cryptography algorithms carefully in their regard to balancing between the security and resource-efficiency to apply in several MIoT uses. Systems operating with electronic health records (EHRs), such as in high-sensitivity applications such as

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implantable devices, may require AES-128 instead of AES-127, despite it having a higher resources requirement. Conversely, a fitness tracker or an environmental sensor application may be effectively served with SPECK or RECTANGLE without significant loss of results in regard to security.

6.2 Implications on future research.

The findings of the study emphasize the necessity to design light cryptographic techniques in order to overcome the given dilemma of MIoT devices within the healthcare sector. Though SPECK and RECTANGLE are a good fit to most of the applications, more research should be done in order to investigate the methods of higher order cryptography like quantum-resistant algorithms that will offer a security guarantee to MIoT devices in the long term as threats will evolve [12], [17].

The future work areas are also seeking environments of the cryptography solutions that are context-sensitive and can dynamically read and adjust their security requirements to the data being transferred and the capabilities of the device. In addition to that, innovative technologies like edge computing and 6G networks could be developed to offer new opportunities to enhance the security and scalability of MIoT systems to enable them to be sufficient to address the growing demands of healthcare data security [12], [16].

6.3 Recommendations

Based on the analysis and findings, it is advisable that as regards the cryptographic algorithm implementation in MIoT devices in the medical sector, the following guidelines should be availed as follows:

- Where Integrity and Confidentiality of sensitive patient data are significant: AES-128 in use in High-Security Applications High-security applications, such as implantable devices or systems that operate EHRs, should use AES-128.
- Resource-Constrained SPECK or RECTANGLE When high power savings and rapid processing are of greater priority than the highest security, e.g., wearables and non-critical medical sensors, can be utilized.
- Future Research: Investigate quantum-resistant cryptography and context-virtual security to satisfy future requirements and threats of MIoT devices in healthcare sector.

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